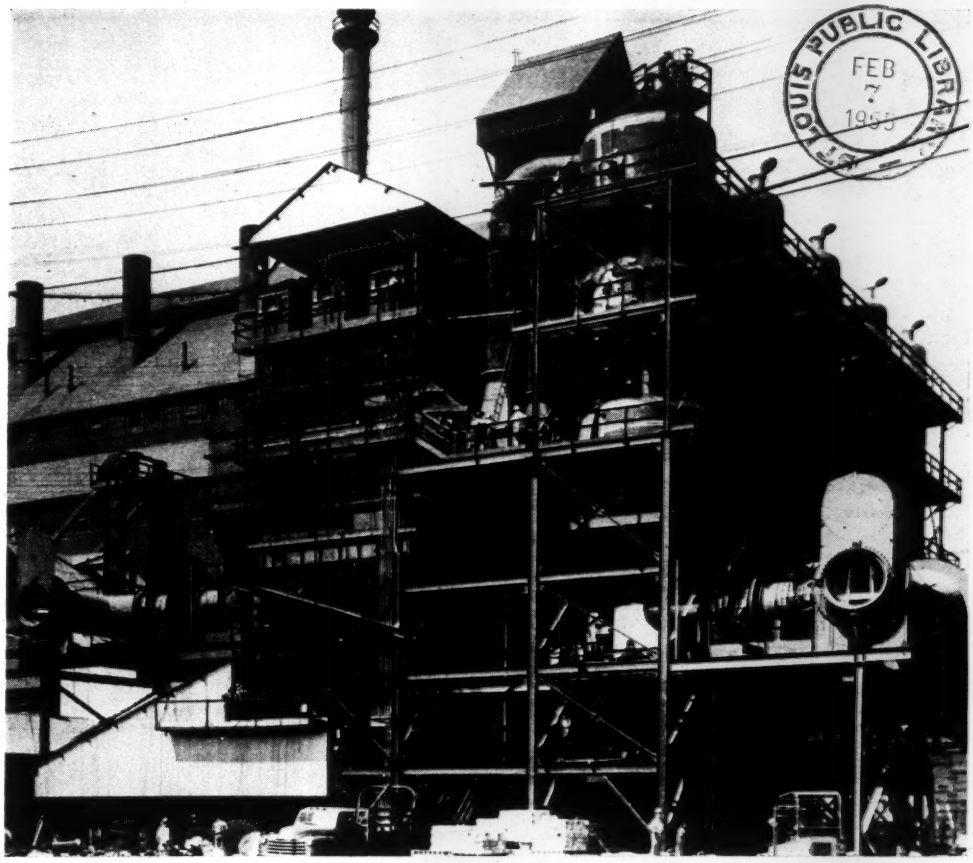
Air Repair



Air Pollution Control in the Steel Industry

(pages 173, 185 and 189)

The Journal of the

AIR POLLUTION CONTROL ASSOCIATION

4400 FIFTH AVENUE PITTSBURGH 13, PA.

FOUNDED 1907

Air Repair

A QUARTERLY JOURNAL DEVOTED TO AIR PURIFICATION

Printed in the United States
Editor: H. C. BALLMAN

Publications Committee 1954-55
HENRY E. ALDRICH, Chairman
B. E. SAWYER, JOSEPH McCABE, D. H. HUTCHISON,
E. Q. CAMP, W. A. CARTER, ROBERT L. CHASS

Technical Review Committee
W. C. L. HEMEON, Chairman
C. A. BISHOP

Copyright 1955
AIR POLLUTION CONTROL ASSOCIATION
4400 FIFTH AVENUE
PITTSBURGH 13, PA.

FEBRUARY, 1955 **Vol. 4, No. 4**

CONTENTS

The Ferro-Manganese Gas Cleaning Installation at Duquesne Works . . . . . *C. H. Good* 173

Atmospheric Pollution Studies with Particular Reference to the Detroit-Windsor Area . . . . . *M. Katz* 176

Conquering the "Phantom" of Air Pollution . . . . . *S. E. Back* 184

Air Control and Research Program of the Kaiser Steel Corporation . . . . . *J. H. Smith, G. L. Rounds* 185

Air Pollution Control As in Effect on the Canadian National Railways . . . . . *C. R. Patterson* 188

Technical Aspects of High Temperature Gas Cleaning for Steel Making Processes . . . . . *L. Silverman* 189

Control of Air Pollution from Oil Refineries in Los Angeles County . . . . . *C. V. Kanter, I. S. Deckert* 197

Dust & Fume Problems in the Cement Industry . . . . . *R. O'Mara, C. Flodin, R. Plass* 203

Twenty Years of Air Pollution Control in Chattanooga . . . . . *E. P. Poste* 210

Evaluation of The Multiple Spot Discoloration Tester . . . . . *T. D. Price, H. Klemperer* 213

The Use of an Impingement Baffle Scrubber in Gas Cleaning and Absorption . . . . . *R. Kopita* 219

Filtration of Radioactive Aerosols by Glass Fibers . . . . . *A. G. Blasewitz, B. F. Judson* 223

Discussion of Paper in November AIR REPAIR
Performance of Three Types of Fabric Dust Collectors 230

The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of the opinions expressed herein.

AIR REPAIR is published quarterly by the Air Pollution Control Association, with editorial and executive offices at 4400 Fifth Avenue, Pittsburgh 13, Pa. Printed in U.S.A. by General Press Corporation and entered at the Post Office, Tarentum, Pa., as third class matter, P. L. & R. 34.66.

The Ferro-Manganese Gas Cleaning Installation at Duquesne Works

C. H. Good
U. S. Steel Corporation

For many years the equipment used in steel plants for cleaning ordinary, basic blast furnace gas has been fairly well standardized. The gas leaving the furnace is first conducted through a simple dustcatcher, where the large particles are removed. Next, the gas then containing 4-5 gr. dust/scf. is passed through tower scrubbers, where, by water entrainment, the dust content is lowered to about 0.2 gr./ft^3. In the more modern plants the final cleaning is effected by passing the gas leaving the tower scrubbers through a tubular type precipitator where the dust is electrostatically collected on the inner surface of a nest of verticle pipes which are the collecting electrodes. Removal of the dust is accomplished by a continuous flow of water over the collecting surface. This method of secondary cleaning produces a final dust content ranging from 0.005 to 0.01 gr./ft^3. In the older cleaning installations, gas from the tower scrubbers is passed through fans equipped with water sprays to obtain a cleanliness of .03 to .05 gr. for use in blast furnace stoves, then through Thiessen washers or disintegrators to obtain a cleanliness of 0.005 gr./ft^3. for use in gas engines.

All of the above standard cleaning methods are dependent upon water for final entrainment and removal of the dust. For basic blast furnace gas, the use of water is entirely satisfactory since the wet dust does not cake and clog the equipment and can be removed in settling basins or thickeners to the extent necessary to prevent stream pollution by the effluent water.

The dust contained in ferro-manganese blast furnace gas, however, is so vastly different from basic gas that none of the standard, commercially available equipment was adaptable to this cleaning problem.

The dust contained in ferro-manganese gas is more correctly termed a fume since the extremely small particles are apparently formed by a process of vaporization and condensation. The particle size leaving the furnace dustcatcher varies from 0.1 to 1.0 micron, averaging about 0.3 micron or 0.00001 in. in size. The quantity of fume is approximately twice that found in basic blast furnace gas. After passing through a dustcatcher the gas contains approximately 8 gr. dust/scf. Other differences between ferro-manganese and basic gas include temperature and moisture content. The normal temperature of the gas leaving a basic blast furnace is approximately 350°F. A ferro-manganese furnace (which uses more than twice as much coke per ton of product and is supplied with blast air at 1500-1600°F.) operates at much higher temperatures than a basic furnace. Water must be sprayed into the furnace above the burden to prevent damage to the furnace top, bell and hopper. By thus controlling the temperature of the gas leaving the furnace to 650°-750° F., the moisture content of the gas averages 15-20%, and, at times, is as high as 30%.

When wetted in the standard cleaning equipment, the ferro-manganese gas fume forms a hard, cement-like deposit. Furthermore, once entrained in the conveying water, the fume cannot be entirely removed by any of the commercially available settling or thickening equipment. A complex water treatment plant would be required to prevent stream pollution by the effluent water.

U. S. Steel Corporation's Research and Development Organization has, during the last 17 years, conducted extensive experimental work in cooperation with equipment manufacturers to develop a practical method of cleaning ferro-manganese gas and handling the dust removed from the cleaning equipment. The installation described in this paper is the end result of that development work.

Fig. 1 illustrates the magnitude of the atmospheric pollution formerly attending ferro-manganese production. This furnace at Duquesne Works, producing 320 tons of ferro-manganese per day, generates 60,000 cfm. of gas containing approximately 12 gr. fume/ft.^{3} This discharge

Fig. 1. Ferro-Manganese Blast Furnace at Duquesne Works.

Fig. 2. The Gas-Cleaning Plant.

of a light, floury, grey dust, was obviously not promoting U. S. Steel's "good neighbor" policy in the vicinity of the plant.

Abatement Efforts

While experimental work to develop adequate cleaning equipment was being conducted, every attempt possible was made to minimize atmospheric pollution and to utilize the gas in boilers.

Since about 15% of the dust can be removed in the ordinary blast furnace dustcatcher, an attempt was made to close the furnace-top bleeders and conduct the ferro-manganese gas through the dustcatcher, mix it with "rough" basic blast furnace gas and burn the mixture in boilers designed for dirty basic gas. This method of operation was discontinued because the gas passages could not be kept open, even with continuous hand lancing. Furthermore, in the gas main, at the points where the ferro-manganese and basic gas were mixed, a hard cement-like deposit formed which almost completely clogged the mains.

Next, a separate gas main was provided so that the ferro-manganese gas could be isolated to 2 or 3 boilers. Continuous hand lancing with high pressure water was necessary to clear the hard, sintered deposits from boiler gas passages. Combustion was very poor. Even while using large quantities of coke oven gas for pilot flames, there were many instances of complete loss of ignition in these boilers.

Next, realizing that we were not significantly decreasing atmospheric pollution and were damaging boilers by attempting to burn the dirty ferro-manganese gas, a 6 ft. diam. bleeder stack was built, discharging at the highest point in the plant. This stack had the effect of dispersing the fume over a wider area and decreasing the concentration in the immediate vicinity of the plant. However, the discharge was accentuated by the fact, that, in complying with local smoke abatement ordinances, other smoke producing facilities in the plant had been effectively corrected. The ferro-manganese gas discharge was accentuated by contrast with an otherwise fairly clean industrial atmosphere.

Gas-Cleaning Installation

Meanwhile our Research and Development Organization had constructed a pilot plant at the Isabella Furnaces where the requirements for both cleaning the gas and handling and treatment of the dust after removal from the precipitators were determined.

The pilot plant unit had a gas-handling capacity of only 3,000 cfm. and consisted of a dry plate type precipitator 10 ft. in diam. and 14½ ft. high, a conditioning tower 5 ft. in diam. and 12 ft. high, along with kilns, mix-mullers, and a briquetting press to process 150 to 200 lb. dust/hr.

Fig. 2 shows the final plant erected at Duquesne Works and placed in operation during July, 1953. Gas-handling capacity is 135,000 scfm. The 5 precipitators, conditioning towers and dust-handling equipment occupy a ground area approximately 150 feet square. Total height of equipment above ground level is 90 ft.

The expected cleaning efficiency is 98% or a minimum dust loading in the cleaned gas of 0.15 gr./scf. We are now cleaning 135,000 cfm. of gas produced by two ferro-manganese furnaces and are collecting approximately 105 tons of dust per day from the precipitators.

Fig. 3 shows the meter and annunciator panels used for control of gas flow, dust preparation and conveying equipment.

Fig. 3. Meter and Annunciator Panels.

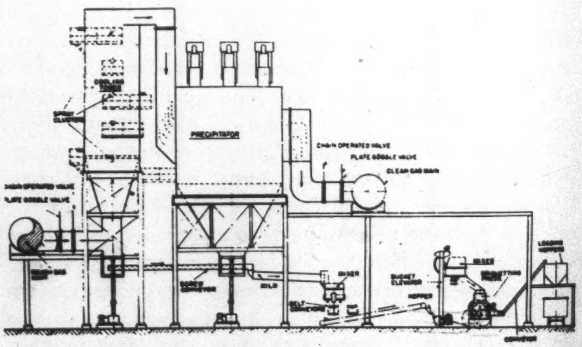


Fig. 4. Diagrammatic Cross-Section of Gas-Cleaning and Dust-Treating Equipment.

Fig. 4 is a diagrammatic cross-section of the plant showing the major equipment.

At the extreme left is the 8 ft. I.D., brick-lined, incoming rough gas main. The dirty gas enters the bottom of each of 5 conditioning towers through a 5 ft. diam. inlet main provided with a mechanical goggle valve for normal operation and a plate goggle valve to be used only if the mechanical valve is defective. The gas flows upward through the 15 ft. diam. conditioning tower which is 60 ft. high above the centerline of the incoming gas main. The tower is provided with 3 banks of water sprays designed to cool the incoming gas from 700° to 350°F. The spray system was very carefully designed so that the water, sprayed into fine mist, would be completely evaporated into the gas, that no impingement of water on the side walls of the tower would occur, and that no water effluent would result.

Conditioning by humidification was found desirable during the pilot plant experiments to obtain smooth, efficient electrical operation of the precipitator. Any dust accumulated at the bottom of the cooling tower is continuously removed by a dust plow, a star valve and a 6 in. ribbon conveyor. The outer shells of the conditioning towers and precipitators are equipped with magnetic impulse rappers to assure removal of any dust accumulations without re-entrainment in the gas stream. These rappers consist of a solenoid actuated, spring return plunger unit mounted on the outside of the tower shell. Intensity and frequency of rapping action can be remotely controlled.

The gas leaving the top of each conditioning tower is conducted through two 3 ft. 6 in. diam. downcomer pipes to the entrance of the precipitator where a very carefully designed inlet distributing baffle assures reasonably uniform flow through the 20 ft. square flow area of the precipitator.

The precipitators are the dry, plate-type. The 440v., 60c. power supply is transformed and rectified by oil immersed tube-type rectifiers to a potential of 65,000-75,000v. which is impressed across the electrodes to ionize the gas. The discharge electrodes are 3/16 in. square, twisted steel rods, approximately 22 ft. long, suspended from an insulated high tension framework on 10 in. and 8¾ in. centers. The weights hanging from the bottom of each discharge electrode are merely to maintain the position and tautness of the rods. The charged dust particles in the gas stream are attracted to the collecting electrodes, which, in these precipitators, are expanded metal plates mounted parallel to the gas flow and electrically grounded to the shell. The ionized particles adhering to the collecting electrodes are discharged and dropped to the collecting hopper with the help of rapping as previously described.

Returning to Fig. 4, the gas, now cleaned, is conducted out of the precipitator through a 5 ft. diam. discharge line equipped with a butterfly valve for regulating gas flow through the individual precipitator, two goggle valves identical with the inlet valves and thence to the 8 ft. I.D. clean gas manifold supplying the boilers (Fig. 5).

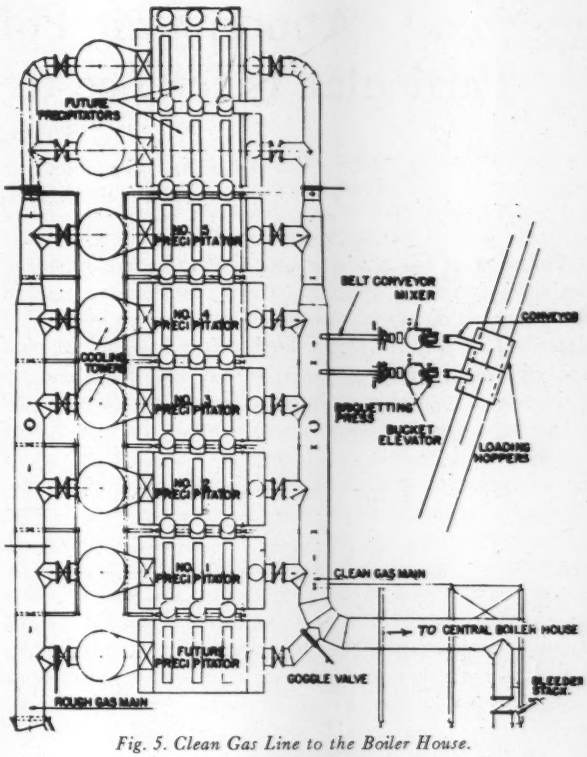


Fig. 5. Clean Gas Line to the Boiler House.

The Dust

The dust is discharged from the precipitator hopper by a dust plow, star valve, and a 12 in. ribbon conveyor.

As removed from the precipitator and cooling tower, the dust is a light, fluffy, grey material which weighs only 12 lb./ft³., contains approximately 21% manganese, 12% alkali and 2% moisture. The dust is also pyrophoric in that it will burn with an exothermic reaction in the presence of air.

5 kilns (1 for each precipitator) are provided to take advantage of the pyrophoric properties of the dust which, in oxidizing, increases in bulk density from 12 to 30 lb./ft³. The kilns, 30 in. in diam. and 20 ft. long are rotated at 10-20 rpm. through a variable speed drive and are provided with an outer shell and with gas under-firing to initiate the oxidation. After the dust has started to burn, gas under-firing is not required.

Leaving the kilns, the hot, burned dust is discharged into 5 water-jacketed, intensive mixers where water is added to agglomerate and cool the dust.

Totally enclosed, 18 in wide belt-conveyors transport the partially wetted dust from the primary mix-mullers to sequentially timed bucket elevators which supply 2 large batch-type, intensive mix-mullers. Here water is again added and mulled into the dust to attain a proper consistency for briquetting.

All conveying equipment is installed in duplicate for maximum reliability.

(Continued on page 183)

Atmospheric Pollution Studies with Particular Reference to the Detroit-Windsor Area*

Morris Katz
Chairman, Canadian Section, Technical Advisory Board
on Air Pollution, International Joint Commission

Pollution of the air by man's domestic and industrial activities is an old problem which has been recognized for hundreds of years. The evils of the smoke of London described in John Evelyn's book "Fumifugium" in 1661 are still the subject of investigation and discussion by British experts today. Advances in modern science and technology have enabled us to learn more about the nature of this baffling problem but have not solved it. In the meantime the trend towards increasing industrialization, growth of large cities and the greatly expanded use of fuels, metallurgical, chemical and other manufactured products have resulted in pollution problems in areas where none existed previously. Within the last decade it has become apparent that substantial control or abatement of air pollution must be achieved in large industrial centers or further progress will be stifled. Disastrous smogs from excessive air pollution have caused illnesses and deaths of considerable numbers of persons. The less spectacular effects consist of huge economic losses to industry and the public by soiling and staining of surfaces, textiles and laundry, deterioration of stonework and paints, excessive corrosion of metals, damage to other materials of construction, and injury to agricultural crops, forests and soils.

Highly polluted communities suffer from repeated visitations of smog, accompanied by eye or throat irritation, odor nuisances, reduced visibility and costly traffic dislocation on city streets, highways and airports. Such conditions present a challenge to the scientist, the engineer and technical groups interested in pollution abatement. Within the past five years, significant contributions have been made to our knowledge of the subject in technical conferences and symposia on methods of investigation, analytical techniques and instrumentation, design of collection and control equipment, meteorological aspects and toxicological effects on plants and animals.

Nature of Atmospheric Contaminants

An arbitrary definition of atmospheric pollution is the excessive loading of the air with foreign matter which causes damage to property or effects the well-being of the individual. Natural contaminants include volcanic ash, soil or sand particles, sea salt nuclei, pollen, plant matter and air-borne micro-organisms. Contaminants due to the varied activities of man include a large number of known compounds and probably a much longer list of products of unknown or indefinite composition. It includes the products of combustion of solid, liquid and gaseous fuels, the waste discharges from metallurgical, oil refinery and chemical operations, incinerators, rubber, pulp and paper, and numerous other manufacturing processes. The aggregate of these atmospheric waste products over a large city may reach many thousands of tons daily in the content of SO_2 and organic vapors alone.

Contaminants may be classified simply into two types:

1. Gases or vapors including the permanent gases and those compounds that have boiling points below about 300°C.

2. Particulate matter consisting of solid and liquid substances. These particulates may be subdivided further into relatively large particles of about 20 to 100μ in size or larger and aerosols or suspensions of finely divided particles ranging in size down to less than 0.1μ.

Aerosols generally include, by definition, all solid and liquid particles in the diameter range from about 0.01 to 100μ. Fog or mist consists of liquid particles, mostly water if of natural origin. Fume is formed by high temperature volatilization or by chemical reaction. Dust consists of solid particles only, resulting from mechanical operations and natural processes that involve dispersion and disintegration of material. Smoke is produced during combustion and destructive distillation operations and may contain either solid or liquid particles.

The physical properties of aerosols are of considerable importance in air pollution because of their influence on visibility, coagulation, deposition, electrical behavior, diffusion and physiological effects. The properties of aerosols have been reviewed by Johnstone.[8] One of the most important characteristics of small suspended particles is the lowering of visibility by scattering of light. The amount of light scattering depends more on the particle size and the refractive index of the material than on the number of particles per unit volume. For most liquid aerosols the size which is most effective for scattering light or obscuration of visibility is in the diameter range of 0.3 to 0.6μ [21].

Larger particles are less effective in scattering light but may reduce visibility by absorption of light. The number concentration of suspended particles per unit volume in a polluted atmosphere may be extremely large, although

* Contributed as D.R.C.L. Report No. 148, Defence Research Board, Defence Research Chemical Laboratories, Ottawa, Canada.

8. Johnstone, J. F., *Proceedings U. S. Tech. Conference on Air Pollution*, McGraw-Hill Book Co., New York, 1952, p. 147.
21. Sinclair, D., and Lamer, V. K., *Chem. Reviews, 44*, 345 (1949).

TABLE I
Deposited Matter
(Tons per Square Mile per Month) for a Number of Cities

City	Year	Monthly Average
1. Chicago[14]	1947	61.2
2. Cincinnati[14]	1946	34.0
3. Detroit[14]	1946	51.7
4. Los Angeles[14]	1948	33.3
5. Rochester[14]	1942	26.4
6. Pittsburgh[3]	1951	45.7[a]
7. Toronto[1]		31.7 - 54.2
8. Windsor Industrial[10]	1951	92.2
Industrial-Residential	1951	53.9
Residential-Semi Rural	1951	35.9
9. Birmingham[22]	1939 - 1944	27.8
10. Bristol[22]	1939 - 1944	11.6
11. Glasgow (East)[22]	1939 - 1944	29.6
12. Leeds (Park Square)[22]	1939 - 1943	35.9
13. London (Westminster)[22]	1939 - 1944	29.1
14. Manchester (Philips Park)[22]	1939 - 1944	42.9

(a) Figure based on insoluble weights only, soluble solids are neglected.

the mass concentration may be low in comparison with that of gas contaminants. Thus at an aerosol concentration of 0.1 mg./m^3, assuming unit density, this would correspond to 45 million particles/ft^3. Even in relatively clean air aerosol particles numbering several million/ft.^{3} may be present.

The size of aerosols has an important bearing on the penetration of particles beyond the respiratory passages into the lungs. The coarser material is excluded by the nasal passages so that few particles may pass if they are larger than 10μ in diameter. Below 5μ the penetration into the lungs increases rapidly but when the size becomes less than about 1μ the retention in the lung begins to decrease. Very small particles penetrate readily but only a small fraction is retained in the lung.[8]

Recent Developments in Environmental Studies

The older literature on studies of the environment was concerned chiefly with dustfall, smoke (suspended particulate matter) and SO_2. Some representative values for dustfall in cities of North America and Great Britain are shown in Table I. The Windsor dustfall is higher than that of many other cities.

Recent investigations have been concerned with a considerable variety of gaseous compounds and organic vapors. The mean concentrations and the range of gaseous pollutants in the air of a number of communities are given in Table II. The data have been gathered from papers by Cholak[2], Katz[9], and the annual reports of the Los Angeles County Air Pollution Control District[13].

The Windsor, Ontario, SO_2 data shown in Table V are based on average concentrations of 30 minutes' duration in continuously recorded observations. Short period peaks of less than 30 minutes' duration during Windsor-Detroit smog periods have reached levels above 0.5 ppm. on many occasions with maxima between 1 and 3 ppm. High aldehyde concentrations have also been found in this Detroit River area, comparable to the values reported for Los Angeles. Concentrations of ammonia and oxides found in the Windsor area are also higher than those reported for other communities.

The concentrations of aerosols in the atmosphere of various communities are indicated in Table III. The complexity in composition of these aerosols is illustrated by the large number of elements found in the particulates by chemical and spectrographic analysis, as shown in Tables IV and V. The data for Cincinnati, Windsor, and other communities are arranged in relative order of abundance of these elements. Significantly more calcium, iron, lead, copper and cadmium are found in the particulates of Cincinnati than in Windsor. A relatively high amount of zinc and cadmium has been reported in the suspended particulates at Donora, Pa.

Although a considerable proportion of the aerosols in a

1. Allcut, E. A., *Eng. J. (Canada), 30,* 154, (1947).
2. Cholak, J., *Proc. Second National Air Pollution Symposium,* Pasadena, Calif., 1952, p. 6.
3. City of Pittsburgh, *Dept of Public Health Report,* 1951.
8. See footnote (8) page 176.
9. Katz, Morris, *Proceedings of the Second National Air Pollution Symposium,* 1952, pp. 95-105.
10. Katz, Morris, *Am. Ind. Hyg. Assoc. Quart., 13,* No. 4, 211 (1952).
13. Los Angeles County Air Pollution Control District, Los Angeles, Calif., *Ann. Repts.,* 1948-51.
14. McCabe, L. C., Mader, P. P., McMahon, H. E., Hamming, W. J., and Chaney, A. L., *Ind. Eng. Chem., 41,* 2486 (1949).
22. "The Investigation of Atmospheric Pollution," *D. S. I. R., 26th Report,* London, Eng., 1949.

TABLE II
Concentration of Gaseous Pollutants in the Atmosphere of a Number of Communities

Community	Oxides of Nitrogen (ppm. NO_2)		Aldehydes (ppm. Formaldehyde)		Chloride (ppm.)		Ammonia (ppm.)		Sulfur Dioxide (ppm.)		Fluoride (ppm. HF)		Oxidant	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Baltimore	0.05-0.79	0.26	0.025-0.12	0.067	0.001-0.11	0.037	0.005-0.053	0.018						
Industrial									0.01 -0.46	0.074	0.00-0.08	0.018		
Rural									0.00 -0.11	0.023	0.00-0.021	0.008		
Cincinnati	0.00-0.55	0.23	0.00 -0.27	0.070	0.00 -0.19	0.033	0.00 -0.089	0.023						
Industrial									0.00 -0.46	0.064	0.00-0.025	0.005		
Residential									0.00 -0.27	0.044	0.00-0.025	0.006		
Donora	0.00-0.63	0.15	.....	.....	0.00 -0.3	0.071	.....	.....	0.00 -0.50	0.15	0.00-0.03	0.006		
Los Angeles	0.00-0.50	0.10	0.00 -1.0	0.18	.....	.....	0.15	.....	Trace-0.60	(0.05 | 0.20)[a]	0.00-0.025	0.008	-0.56	(0.07 | 0.35)[a]
Windsor[b]	0.03-3.48	0.89	0.00 -0.85	0.20	0.00 -0.618	0.095	0.02 -3.070	0.216						
Industrial									0.00 -1.454	0.093	.....	.....		
Semi-rural									0.00 -0.876	0.006	.....	.....		

(a) Mean for days of good visibility and reduced visibility respectively, in Los Angeles.
(b) 1951-52 values.

TABLE III

Concentration of Suspended Particulate Matter (mg./m.³) in the Atmosphere of a Number of Communities[2-9]

Community	Minimum	Maximum	Mean
Baltimore			
downtown area	0.21	1.72	0.87
industrial area	0.05	1.46	0.38
Cincinnati			
industrial area	0.01	1.98	0.42
residential area	0.01	1.30	0.28
Donora	0.00	2.50	0.74
Los Angeles, Detroit, San Francisco, Washington	0.25	0.47	0.51
Windsor[a] areas			
high pollution	0.036	0.47	0.21
moderate pollution	0.001	0.56	0.15
low pollution	0.003	0.21	0.08

(a) Oct.-Dec. 1951

polluted atmosphere consists of fine carbon particles and miscellaneous organic matter, the inorganic fraction contains a substantial number of compounds which may be of considerable significance. Some of these have been isolated and identified recently by x-ray diffraction technique in samples collected in the Windsor area[10]. The fine particulate matter in the atmosphere of Detroit has been studied by Clayton[5] with results comparable to those obtained in the Windsor area, although the total mass concentrations per unit volume are higher.

Considerable study is being devoted at the present time to two atmospheric pollution problems which have certain unique features. A group under a joint technical Advisory Board for the United States and Canada has been engaged for some years in an investigation of air pollution in the Greater Windsor-Detroit area for the International Joint Commission. In the Los Angeles area the smog problem has been under investigation for about 5 years by groups of scientists and engineers of the local Air Pollution Control District, the Stanford Research Institute, and a number of Universities in California.

International Windsor-Detroit Problem

In 1949, upon receipt of complaints from the cities of Windsor and Detroit and citizens in the area that the atmosphere was being contaminated by excessive amounts of smoke, soot, fly ash and other impurities in quantities detrimental to the public health and welfare and to property interests on either side of the international boundary, the problem was referred to the International Joint Commission. The terms of reference were broad in scope and involved an investigation of the major sources of pollution, including smoke from Great Lakes vessels plying the Detroit River as well as the varied effluents from industrial operations. The questions to be answered involved the determination of the possible effects of air

2. See footnote (2) page 177.
5. Clayton, G. D., *Proc. Second National Air Pollution Symposium*, Pasadena, Calif., 1952, p. 110.
9. See footnote (9) page 177.
10. See footnote (10) page 177.

TABLE IV

Average Composition of Suspended Matter (μg./m.³) in the Atmosphere of a Number of Communities[2-10]

Element	Baltimore	Cincinnati	Donora	Los Angeles	Windsor
Silicon	-	-	-	2.5 - 6.0	6.21
Calcium	-	16.0	-	2.5	3.26
Aluminum	4.0	4.4	6.0	2.5 - 6.0	2.75
Iron	15.1	12.5	14.0	2.5 - 6.0	2.49
Magnesium	-	7.0	-	1.1 - 2.5	0.81
Lead	1.0	2.7	4.5	0.8 - 6.0	0.614
Manganese	0.3	0.3	0.6	tr. - 0.24	0.281
Copper	0.4	0.86	1.0	0.1 - 0.24	0.247
Zinc	-	2.0	40.0	-	0.197
Titanium	0.5	1.0	-	tr. - 0.24	0.067
Tin	0.2	0.2	0.2	-	0.046
Molybdenum	-	-	-	-	0.034
Barium	-	-	-	0.1 - 0.24	0.027
Nickel	-	-	-	-	0.026
Vanadium	0.2	0.2	-	-	0.017
Chromium	-	-	-	-	0.011
Cadmium	0.2	0.22	2.0	-	0.008
Beryllium	0.0005	0.0095	-	-	0.006

contaminants on public health, safety, vegetation and property, and identification of the major sources responsible, if any. Furthermore, if vessels were found to be creating an excessive amount of pollution, the most practicable remedial measures were to be determined, as well as the cost of such measures and by whom such cost should be borne.

The area under investigation lies on both sides of the Detroit River for a distance of about 30 miles and extends to about 15 miles inland from the river. The estimated population on the Michigan side is about 2,775,000 and on the Canadian side about 160,000. This region contains the third largest concentration of industry in North America. Although the automotive industry occupies a dominant position in both Detroit and Windsor, there are large manufacturing operations which produce steel and pig iron, heavy chemicals, paints and varnishes, pharmaceuticals, electrical appliances, stoves and furnaces, brass and iron foundry products, machine and cutting

TABLE V

Composition of Suspended Matter (μg./m.³) in the Atmosphere of Cincinnati and Windsor

Element	Cincinnati			Windsor		
	Min.	Max.	Mean	Min.	Max.	Mean
Silicon	-	-	-	1.05	20.84	6.21
Calcium	0.4	65.0	16.0	0.85	13.88	3.26
Aluminum	0.1	25.0	4.4	0.71	6.94	2.75
Iron	0.1	110.0	12.5	0.59	8.77	2.49
Magnesium	5.0	10.0	7.0	0.20	2.64	0.81
Lead	0.1	11.5	2.7	0.125	1.805	0.614
Manganese	tr.	2.0	0.3	0.064	0.910	0.281
Copper	0.01	32.0	0.86	0.013	0.830	0.247
Zinc	0.1	14.0	2.0	0.00	0.89	0.197
Titanium	0.1	20.0	1.0	0.005	0.18	0.067
Tin	0.0	12.0	0.2	0.011	0.110	0.046
Molybdenum	-	-	-	tr.	0.087	0.034
Barium	-	-	-	0.00	0.18	0.027
Nickel	-	-	-	0.006	0.069	0.026
Vanadium	0.2	0.4	0.2	0.00	0.28	0.017
Chromium	-	-	-	0.00	0.042	0.011
Cadmium	0.1	0.42	0.22	0.001	0.046	0.008
Baryllium	0.0001	0.06[a]	0.0095[a]	0.00	0.073	0.006

(a) Dubious Values

tools, synthetic resins and plastics, solvents and organic chemicals, rubber products and adhesives, caustic soda, calcium chloride and chlorine, salt and soda ash, phosphoric acid and phosphate, pulp, paper and refined petroleum products.

During the navigation season the Detroit River carries probably the largest vessel traffic in the world. The vessel fleets of the Great Lakes make about 30,000 passages of the Detroit River in transporting an enormous volume of cargo including iron ore, coal and grain.

The annual domestic and industrial consumption of coal and solid fuels is estimated at about 15,000,000 tons on the U. S. side and 650,000 tons on the Canadian side of the international boundary. In addition there is the solid fuel consumed by vessel traffic on the Detroit River. This yields a total consumption of about 16,000,000 tons annually. On the basis of an average sulfur content of 1.5% and the release of about 90% of this sulfur to the atmosphere during combustion, it is estimated that approximately 430,000 tons of SO_2 are discharged to the atmosphere annually from solid fuels alone. This total is augmented further by the SO_2 released in the combustion of liquid and gaseous fuels.

Many other contaminants are released to the air as solids, liquids, gases and vapors in substantial quantities from public and industrial operations. These include: (1) smoke, soot, fly ash, organic and tarry matter from products of combustion; (2) carbon monoxide, hydrocarbons, aldehydes, peroxides and organic acids from internal combustion engines; (3) sulfur compounds, including sulfur trioxide, sulfuric acid and hydrogen sulfide; (4) fluorine and chlorine compounds, oxides of nitrogen, nitric acid and ammonia; and (5) metallic fumes, oxides, and dusts from metallurgical, chemical and mechanical operations.

The environmental studies have been designed to correlate with micrometeorological investigations and to delineate areas of high, intermediate and low pollution. SO_2 pollution has been found to vary in intensity and frequency according to a pattern which shows diurnal as well as seasonal trends. The daily cycle of aerosol pollution also exhibits a diurnal variation, with a well-defined peak in the early morning falling to a minimum in the early afternoon and rising during the night. This follows the cycle of temperature lapse rate and turbulence[9-11]. There is a correlation between intensity of SO_2 and high concentrations of suspended particulate matter.

Smog visitations of several hours' to several days' duration have been noted during temperature inversion periods that are most frequent during the months of April, May, July, October, November and December. On many occasions the greatly reduced visibility, accompanied by higher than usual contamination, has been noted for a distance of 15 miles inland from the Detroit River. A number of such visitations caused eye irritation to residents of the area. Crop damage and injury to shrubs, ornamental plants and trees have been observed.

One of the foremost problems in this area has been the excessive emission of smoke from vessels plying the Detroit River. Thousands of observations have been made by trained observers, using the Ringelmann Chart method, in each navigation season since 1949. Smoke abatement efforts have been rewarded by a marked improvement in smoke performance from 1951 to date. The percentage of the time of smoke observations from vessels corresponding to No. 3 Ringelmann and darker, which amounted to about 51% for the 1950 navigation season, was reduced to only about 31% by 1952. During the 1953 season there had been a further improvement.

The results have been achieved by securing the cooperation of the Lake Carriers and Dominion Marine Associations in a program of improvement of firing methods and boiler equipment, as well as the institution of a voluntary system of Smoke Emission Objectives, which are revised frequently. These objectives are made more stringent as improved methods and equipment are developed to reduce smoke. Owners of vessels are notified by the Technical Advisory Board if their vessels fail to conform to these objectives, which are designed to meet the best practical performance which may be expected from the various broad classes of boiler equipment presently installed on Great Lakes vessels. Owners are being encouraged to convert hand-fired fuel burning equipment to automatic stokers. It is believed that with proper equipment, burning of solid fuel will give just as good results as liquid fuel in regard to smoke emission. The model A.S.M.E. Smoke Code has been adopted for both oil burning vessels and those equipped with underfeed stokers using solid fuel.

A comprehensive health study is in progress in the Greater Detroit-Windsor area to determine the chronic effects on public health of long-continued exposure to pollutants. The acute effects of smog disasters are well known and have provided dramatic warnings of the danger from the accumulation of foreign material in the air under conditions when natural dispersion and dilution processes fail. The chronic effects on health have never been evaluated conclusively to date on any known population group[15]. During the past 100 years many attempts have been made to apply mortality statistics in order to show the relationship between fog, smoke and smog and

9. See footnote (9) page 177.

11. Katz, Morris, and Clayton, G. D., "Instrumentation and Analytical Techniques for the Continuous Determination of Air Contaminants," (In Press) *Proceedings of the American Society for Testing Materials*, 1953.

15. McCord, C. P., *Ind. Medicine Surgery, 19*, No. 3, 97 (1950).

mortality rates from various diseases[19-20]. Mills[16-17] and others[7] have reported correlations between dustfall and respiratory disease in some cities of the United States. Such statistics can be readily refuted in the absence of data on the nature of the contamination and factors related to the population itself, because the statistics are collected for other purposes.

The methods used in the Detroit-Windsor health study have been reported by Clayton[5] and Peart and Josie[18]. These have consisted of the following steps:

1. A review of existing health data in the Detroit River area for comparison with other cities.
2. A sample morbidity survey to measure and compare the intensity and types of sickness and symptoms in well-defined areas of high and low pollution. The survey has been designed to match sample populations based on socio-economic factors in localized areas which have different pollution levels.
3. Control samples of households have been selected in a population area which is similar to the high and low pollution areas of Windsor and Detroit, except that the level of pollution is less than that of the low pollution areas.
4. Continuous measurements of air pollution levels by the most modern techniques, observations of meteorological factors, and records of ill health in the various study areas are being made concurrently on a "round-the-clock" basis.

Developments in Monitoring Atmospheric Pollution

The greatly increased scope of recent air pollution studies has provided the incentive for vigorous research into new methods of analysis, instrumentation and techniques for the collection, measurement and identification of gaseous and aerosol pollutants. The choice between continuous and intermittent methods of analysis depends upon the nature of the material to be measured, the use to be made of the data, and the influence of meteorological factors on the quantities likely to be present in the air at a given period. Continuous instrumentation techniques are preferable to measure visibility, cycles of pollution by suspended particulates, and major contaminants such as sulfur dioxide, oxidants, etc. Intermittent samples will suffice for identification purposes.

The subject has been reviewed recently by Katz and

TABLE VI

Summary of Analytical Methods and Equipment Used for Determining Common Air Pollutants[4]

Pollutant	Method of Collection and Equipment	Laboratory Procedures
Particle fall	1. Cylindrical glass jar 6 in. diam. by 12 in. high: water + glycerol; Water; Water + alcohol } Traps	Tons/sq. mile/month, combustibles, water solubles, water insolubles; elemental composition by spectrography
	2. Directional dirt fall collector	Same as above
Aerosols or suspended matter	1. MSA electrostatic precipitator	Chemical, spectrographic, polarographic and x-ray, SO_4, F, Cl, SiO_2 and 22 elements
	2. High volume electrostatic precipitator	Same as above
	3. High volume air sampler	Chemical, spectrographic, polarographic, and x-ray, SO_4, F, Cl, SiO_2 and 22 elements
	4. Thermal precipitator	Particle sizing
	5. Standard impinger	Chemical, spectrographic, polarographic, and x-ray, SO_4, F, Cl, SiO_2 and 22 elements, numerical determination and sizing
	6. Midget impinger	Same as standard impinger
	7. Chaney Auto-Sampler	Transmission, reflectance, and spectrographic
	8. Air Sampling Equipment Co., automatic impinger	Same as Auto-Sampler
	9. Automatic smoke filter	Same as Auto-Sampler
	10. Spiral sampler	Particle sizing and x-ray diffraction
	11. Cascade impactor	Particle sizing
	12. Transmissometer	
	13. Chaney visibility meter	
Carbon monoxide	1. Colorimetric CO tester	
SO_2 from total sulfate	1. 0.2 N sodium hydroxide in impinger at 1 ft.^{3}/min.	Transmissivity of barium sulfate
SO_2 per se	2. Alkaline iodine solution in impinger at 1 ft.^{3}/min.	Iodometrically by titration with standard thiosulfate
SO_2 per se	3. Same as 1, except particulates removed by electrostatic precipitator	Same as 1
Particulate SO_4 or H_2SO_4, SO_3	4. Same as 3 and 2	In 3, material collected in each part of train is analyzed as in 1; when 2 is used, an aliquot is treated as in 2. and another as 1, for total sulfate; difference is used to establish partition
	5. Thomas autometer	
	6. Titrilog	
	7. Davis electroconductivity analyzer	

4. Clayton, G. D., *American Gas Association, PC-53-12*, May 1953.

5. See footnote (5) page 178.

7. Heimann, H., Reindollar, W. F., Brinton H. P., and Sitgreaves, R., *Archives Ind. Hyg. Occup. Med., 3*, 399 (1951).

16. Mills, C. A., *Am. J. Hyg., 37*, 131 (1943).

17. Mills, C. A., *Cincinnati J. Med., 27*, 624 (1946).

18. Peart, A. F. W., and Josie, G. H., *Arch. Ind. Hyg. Occup. Med., 7*, 326, (1953).

19. Russell, W. T., *Lancet, 2*, 335 (1924).

20. Russell, W. T., *Lancet, 2*, 1128 (1926).

TABLE VI—(Continued)

Pollutant	Method of Collection and Equipment	Laboratory Procedures
Oxides of nitrogen	1. 5-liter evacuated glass ballon followed by absorption in 0.1 N H_2SO_4 + 3% H_2O_2	Phenoldisulfonic acid for total nitrates α naphthylamine-sulfanilic acid for NO_2 per se
	2. Freeze out sampler with liquid oxygen	Mass spectrometry
Aldehydes	1. 1% $KHSO_3$ in impinger at 1 ft.^{3}/min.	Goldman-Yagoda method for total aldehyde reported as acrolein or formaldehyde
	2. Distilled water in impinger at 1 ft.^{3}/min.	(a) Aliquot analyzed by Ripper method (same as 1 above) for total aldehyde (b) Aliquot by chromotropic acid method for formaldehyde
	3. Freeze out sampler with liquid oxygen	Mass spectrometry
Fluorides	1. 0.2 N NaOH in impinger at 1 ft.^{3}/min.	Alizarin-thorium nitrate-NaF back titration, following distillation
	2. Same as 4 under SO_2 for partition	
	3. High volume air sampler	Perchloric acid
	4. Continuous HF recorder	
Chlorides	1. 0.2 N NaOH in impinger at 1 ft.^{3}/min.	Transmissivity of quantity of AgCl produced
	2. 0.1 N NaOH in impinger at 1 ft.^{3}/min.	Thiosulfate titration
	3. o-Toluidene in impinger at 1 ft.^{3}/min.	Colorimetrically
	4. High volume air sampler	Silver nitrate solution
Ammonia and ammonia compounds	1. 0.1 N H_2SO_4 in impinger at 1 ft.^{3}/min.	Nessler reagent following distillation from alkalinized solution and trapping in H_2SO_4
Ozone	1. 1% KI in 0.1N NaOH in impinger at 1 ft.^{3}/min.	Spectrophotometrically
	2. Oxidant recorder	
Hydrogen sulfide	1. Alkaline zinc acetate in scrubber at 10 *l.*/min.	Colorimetrically by measuring methylene blue color obtained with p-aminodimethylaniline and ferric chloride
	2. Davis electro-conductivity analyzer	

Clayton[11], Clayton[4], Thomas [23], and Kay[12]. Table VI, by Clayton[8], provides a useful summary of the equipment and methods now available for determining the common air contaminants.

4. See footnote (4) page 180.
8. See footnote (8) page 176.
11. See footnote (11) page 179.
12. Kay, K., *Ind. Eng. Chem., 44,* 1383 (1952).
23. Thomas, M. D., *Proc. Second National Air Pollution Symposium,* Pasadena, Calif., 1952, p. 16.

Future Trends in Pollution

Recurrent disasters and the economic and nuisance effects of air pollution have created a wide-spread public interest in this problem. It is becoming evident that in large cities the pollution is caused not only by industrial operations but by all human activities, including domestic fuel-burning and operation of large numbers of vehicles for public and private transportation. However, because of public clamor for control, hasty legislation has been enacted in some instances with the result that private industry has had to undertake uneconomic measures or abandon plans for new plant construction in some cities.

It is probable that future pollution control legislation will become more restrictive. This is inevitable as more knowledge is acquired regarding the toxicity of specific contaminants, and advances in science and engineering make it possible to reduce stack emissions of certain undesirable products. The American Society of Mechanical Engineers has maintained a Committee for many years that deals with the provisions of a Model Smoke Code which is revised periodically. A model ordinance for Canada was proposed recently by a Committee sponsored by the Engineering Institute of Canada[6]. Such codes have the advantage that they are prepared by experts with realistic objectives and some knowledge of the technical and economic factors involved in pollution control.

Other future trends will include forecasting of major smogs, and measures of individual protection in areas troubled with a persistent pollution problem, as in London, England. In severely polluted areas, during prolonged inversion periods, curbs may be placed on the operation of motor vehicles, incinerators, and other public practices. Smokeless fuels only will be authorized. Such measures have been recommended recently by a committee report on anti-smog measures presented to the British House of Commons as a result of the 1952-53 winters' series of smogs that may have caused 12,000 deaths in London.

Recent devices for protection and control in the Los Angeles area include a charcoal filtration unit for home air conditioning and a proposed filter and catalyst to remove aldehydes, carbon monoxide, oxides of nitrogen and other objectionable effluents from the exhaust gases of automobiles, buses and trucks.

Air pollution will be of increasing importance in planning of cities and industrial communities. Meteorological and topographical factors will be taken into account in community planning in relation to location of industrial and residential areas. Industry will be decentralized and, in certain areas, residences will not be allowed too close to certain types of heavy industrial operations. Industry will be protected against the unreasonable encroachment of residential developments and vice versa. Certain types of industry will be permitted to use only certain land

6. Committee on Atmospheric Pollution in Canada, *Report, Engineering Journal, (Canada) 34,* 448 (1951).

areas based on the ability to control objectionable contamination. Zoning of areas will include more extended use of land for public parks, gardens and wooded areas to prevent overcrowding of sources of emission.

DISCUSSIONS OF PAPER BY MORRIS KATZ ENTITLED "ATMOSPHERIC POLLUTION STUDIES WITH PARTICULAR REFERENCE TO THE WINDSOR-DETROIT AREA"

I would call attention to Table IV in Mr. Katz' paper where he lists a number of cities and gives the average monthly dust fall in each. As a matter of comparison such figures have no meaning. The fuel varies in these cities; one uses coal, another gas or oil, which will naturally make a very different deposit. Again, industries are different, some cities having steel mills, others mostly chemical manufacture; meteorological conditions vary; and different collecting methods are used. There seems to be no standard.

Mr. Katz has touched on many points in his paper and I want to emphasize in a short discussion a few of them relating to the health angle.

The Health Aspect of Air Pollution

There seems to be a general impression, when we have a catastrophe such as have occurred in London and Donora, that the cause of deaths was due to sulfur dioxide in the air. Many assume that SO_2 becomes SO_3 and then in contact with moisture turns into sulfuric acid.

Many doctors disagree. They say that such a high percentage of deaths could not come from sulfur alone—that other toxic agents must have been present. The only record we have is the SO_2 determined during the London fog. No other determinations of toxic materials were made during the fog except CO which was due to concentration of automobiles and did not cover the general area.

Why do we assume it is sulfur? Chiefly because we can taste it, smell it and it irritates our throat. What about oxides of nitrogen? These can neither be tasted, smelled nor seen. We do not know when we breathe them and they are extremely dangerous.These remarks apply also to cadmium, antimony and many other very toxic agents.

In the February 1954, issue of "Public Health," published by the American Public Health Association, is an article written by Dr. Frank Princi on the Health Aspects of Atmospheric Pollution. He says, "A critical examination of the various investigations, including the London fog records, shows that neither the postulate of synergistic activity nor the theory of pulmonary irritation have as yet been demonstrated."

Probably sulfur had something to do with it, but were 4,000 deaths due to sulfur only?

As Dr. Princi further says, many toxic materials may be absorbed by our respiratory tracts and exert their effects on the other organs, yet death may be registered as cardio-respiratory. In other words, sulfur may be present and produce irritation and yet not be the cause of death. This means that in the present state of our knowledge we need information on air pollutants.

For example, do we know that carbon smoke is harmful? It is a nuisance, yes; but it is not proved that smoke affects our respiratory system. Does it produce catarrh? The doctors disagree.

The late Dr. Samuel R. Haythorn, for many years in charge of the laboratory work of the Allegheny General Hospital in Pittsburgh, made a study based on some 2,500 post-mortem examinations of lungs. In his published records he states his conclusion that carbon does not predispose to tuberculosis. Another point of interest is that particles such as silica, for instance, must be between 1 and 10 microns in size in order to do damage and that the weight of the particle or its shape has nothing to do with it.

It is true that we have some published data (how reliable, I do not know) on certain elements and compounds, giving the amounts that taken into the human system are dangerous. But how about small quantities? Can a man live in them indefinitely? How injurious is prolonged exposure to small quantities of toxic substances? What accurate information has the physician about the effects of dusts? Perhaps something about silica. How about nickel, copper or even iron ore dust? What is the lower danger limit? And what affect does the size of the particle have? We need more information, more investigation. It may require a long time to get it. In the meantime, I cannot say enough in praise of the research work being done by Leland Stanford and a few of our other larger universities.

As an example of the difficulty in obtaining accurate information on this subject, we attempted at one time to compare death rates in a dirty section of Pittsburgh with those in a clean section. The dirty section had the higher death rate, but we could not conclude that this difference was due to air pollution. The death rate might be affected by the occupation of the individual, his diet, his habits, the type of house he lives in. There are numerous factors that must be taken into account as well as air pollution.

Then too, the records are not complete. Suppose a man has pneumonia and this affects his heart. Now what did he die of, pneumonia or heart disease? The doctor should record the primary cause, but doctors may not agree.

This discussion is merely to indicate our lack of knowledge, that air pollution study is comparatively new, and that we need a real correlation between health and air pollution.

SUMNER B. ELY
Bureau of Smoke Control
Pittsburgh, Pa.

The task of discussing this paper is a difficult one. The paper contains much data abstracted from a wide range of source material. It also contains a great deal of what may be termed "editorial opinion" on many phases of the air pollution problem that few who are not deeply enmeshed in the administration of a comprehensive air pollution control program are likely to be able to evaluate fully. This paper, and similar papers presented at our conferences, are extremely valuable for the usable information they contain. There are some features of this paper, however, that may be in need of clarification.

Terms are used in different places with different meanings. Typical of this is the word *aerosol* which, in one section, means particles between 100μ and 0.01μ, and in another section means particles between 20μ and "less than 0.1μ." It might also be pertinent here to mention that *particulate matter* is now quite generally being used by many authors in several different ways. For example, in this paper particulates are, in one section, defined as the solid and liquid particles below 100μ and above 20μ, as distinguished from the same section's definition of aerosols. In publications of the International Joint Commission's Technical Advisory Board on Air Pollution the phrase *total particulate matter* is used to describe the group of particles filtered in an AEC high volume sampler after the sample has been oven-dried for 2 hr. at 110°C. It is my impression that the AEC high volume sampler collects very little particulate matter in the plus 50-micron range. In the paper under discussion, this last type of sample is variously called *suspended matter* and *suspended particulate matter*. The need for standardized nomenclature in air pollution work is thus again spotlighted. The work of the APCA and ASTM committees is fulfilling this need.

While I cannot agree with other criticisms of the dustfall data presented here, I consider it unfortunate that such old data were used. I believe the paper would have been greatly enhanced had Hemeon's recent analysis of dustfall data by neighborhood classification been referred to. It might be mentioned here that in the course of Hemeon's work, he found that he could not compare the dustfall data of the three cities that use the Detroit dustfall collector (Detroit, Mich., Windsor, Ontario, and Sarnia, Ontario) with the data from other communities because the shape of the Detroit collector was radically different from the simple shapes used elsewhere. It will be recalled that the Detroit collector was designed in a wind-tunnel for reduced re-entrainment of settled dust, especially when the container bottom is dry.

It may be of interest to know that in the Detroit River area, the communities on both sides of the river have been co-operating closely in many kinds of problem situations (including air pollution) for many years without bothering the state, provincial, or federal governments, except where necessary because of legal and legislative requirements. Detroit and Windsor, especially, have had intimate and friendly relationships for many years. With respect to the land-based air pollution control work, their programs are remarkably parallel with a free interchange of information, ideas and personnel training, and with a very few trans-boundary air pollution complaints that are handled with dispatch.

But the communities of Detroit and Windsor, and others, including Wyandotte, Mich., went to their Federal Governments and the International Joint Commission only because the control of ship smoke and fly ash could not otherwise be accomplished, since local legal jurisdiction was inadequate on the international waterway, the Detroit River. The development of the area-wide study of "all effects from all pollutants from all sources" was an interesting surprise to the originators of the simple request that smoking, fly-ash-emitting ships plying the Detroit River be cleaned up. The study seemed to offer the opportunity for obtaining useful information, and so the communities joined in and (on the United States side, at least) now perform most of the work of the study. Useful results have been slow in coming, possibly because so much of the study's efforts have been

devoted to measuring the contaminants in the atmosphere. Only recently has the emphasis begun to shift to a correlation between the concentrations of contaminants and the types and degrees of effects. An excellent job has been accomplished in relating meteorological factors with concentrations of contaminants. The vegetation effects study is progressing well, also. The health effects study is not yet out of pilot stage, and has aroused much interest because it is unique. The soiling effects study and the sunlight reduction study are also continuing.

The paper discusses future trends in planning and zoning as related to air pollution. While we know that planners have for many years been using information regarding air pollution as one of the factors in guiding the orderly development of our communities, it is just as well to be reminded of this from time to time. In Detroit, new residences have been zoned out of heavy manufacturing areas since 1948. Also, several communities, including some adjacent to Detroit, have enacted air pollution performance standards in their zoning laws during the past 3 years. The use of terrain, meteorology, and total air pollution potential factors in planning future land use has been an interesting development that has received extensive discussion before the American Society of Planning Officials and the Air Pollution Control Association. It has been my privilege to work closely with the Detroit Metropolitan Area Regional Planning Commission during the past few years in the development of their land use plan, in which the air pollution potential factor was given full consideration.

As I said at the start, the task of discussing this paper is a difficult one. The paper contains abstracted data and editorial opinions on many phases of air pollution. It is probably an axiom that editorial opinions arouse controversy. It is one of my own borrowed axioms that any statement is either demonstrable or debatable, but is not likely to be both at the same time.

BENJAMIN LINSKY
Smoke Abatement Bureau
Detroit, Mich.

Reply to Benjamin Linsky

Particulate matter in air pollution is a very general term which is applicable to all particles which find their way into the atmosphere. These may be classified roughly by size into coarse or large particles of about 20 to 100μ in size, and small finely divided particles down to less than 0.1μ. The term *aerosol* is usually used to define an aerial disperse system such as smoke, fume, haze, smog, mist, fog or cloud. Sand storms may contain large particles or particulate matter beyond the size range of true aerosols. The same is true of fly ash. In natural water fogs, where the size of the fog droplets is determined by the concentration of nuclei and the relative humidity of the air, the droplets may range in size from less than 10μ to about 80μ if the concentration of nuclei is small. The internal stability of an aerosol is governed by the phenomena of coagulation and gravity settling. The concentration determines the coagulation rate and the particle size controls the rate of settling.

In the circumstances it is difficult to give hard and fast definitions. However, it is clear from this paper that particulates or particulate matter cover all solid and liquid particles, irrespective of particle size, and are not restricted as to size in the manner quoted by Mr. Linsky.

There is no doubt that a difference of opinion exists among control officials and others concerning the value and significance of dustfall measurements. Nevertheless, measurement of dust fall is the simplest method of assessing the average weight of particles which settle or fall out of the atmosphere at a particular location. Dustfall has been measured for many years in many cities of America and elsewhere as an indication of the relative degree of contamination of the air by fuel, dust or coarse particles. As indicated by Hemeon[1], the most important bar to valid comparisons of dustfall rate between different cities is in the failure to classify and average dustfall figures according to the types of districts in which they were obtained. Hemeon has stated that if the results are averaged for the several months of a single season (and for particular types of districts) the monthly fluctuations dissolve and remarkably stable figures of relatively high significance result. Dustfall measurements in the Greater Windsor area are classified according to the neighborhood in which they are obtained.

Sensenbaugh and Hemeon[2] have made recently a critical analysis of the variables involved in monthly dustfall measurements and have proposed a number of recommendations designed to obtain the most consistent results from the use of dustfall apparatus.

It is recognized that a standard method for dustfall measurements would represent a highly desirable step in the cross comparison of dustfall rates for various cities of North America. In Great Britain the procedure for dustfall was standardized many years ago. However, the importance of size and shape of dustfall collectors may be overemphasized by some critics. Recently, Pond and Paxton (Symposium on Air Pollution of the American Chemical Society, New York, Sept. 14-16, 1954) in a comparison of water jars versus greased plates in dustfall measurements stated that the greased plates gave only slightly higher dustfall rates than did the concurrently exposed water jars. The greased plate procedure gave more reproducible results, with a standard deviation of 7.6% compared to 12.6% for the water jars.

The use of the Detroit type of dustfall collector is being extended to a number of areas in Canada, besides Windsor, and the author hopes to see this type employed more generally in the United States.

The author recognizes the valuable contributions made to the overall study of the International Joint Commission by the City of Detroit and other communities.

1 Hemeon, W. C. L., AIR REPAIR, 2, No. 2, 60 (1952).
2 Sensenbaugh, J. D., and Hemeon, W. C. L., Proceedings Am. Soc. Testing Materials, 53, 1160 (1953).

(Continued from page 175)

Ferro-Manganese Gas Cleaning

The final product, a 2 in. x 2 in. pillow shaped briquette is produced by feeding the batch from the final mix-mullers through the die rolls of two briquetting presses under 40 tons roll pressure. The briquettes are then conveyed to overhead storage bins by endless chain bucket conveyors. The briquettes are at present being stocked in outside storage piles. Meanwhile, additional processing requirements to remove alkali and otherwise make the material suitable for recharging in blast furnaces are being studied.

Operating personnel required for the plant consists of a crew of 3 men per turn, 1 operator and 2 helpers.

As in the initial operation of all completely new processes, many operating problems have developed, some as yet not completely solved.

The original rappers for removal of dust accumulations on the discharge electrodes of the precipitators were found to be inadequate. Heavy duty pneumatic rappers are now being installed to remove this deposit which, by shortening the electrical path between the electrodes, has limited the power input which can be applied without flash-over. Excessive breakage of high tension insulators within the precipitators was experienced during the first few months of operation. This problem was eliminated by shortening the steam purging cycle and by avoiding direct water impingement on insulators when cooling down the units for inspection.

Although these operating problems have involved outages of individual equipment, the reliability of the cleaning plant as a whole has been excellent. Since initial operation on July 16, 1953, the plant has been off the line for only 20 minutes. This was during an unavoidable failure of the incoming power system.

This performance indicates the achievement of a practicable solution of the problem of cleaning ferro-manganese gas at Duquesne.

Conquering the "Phantom" of Air Pollution

S. E. Back
The Pennsylvania Railroad
Philadelphia, Pennsylvania

The "Phantom" has for many years disguised himself as smoke, gases, fly ash, dust, etc., polluting the very air in which we live and move and have our being. The railroads of the United States (including the Pennsylvania Railroad) have spent a large fortune in conquering the "Phantom" of air pollution in the past thirty years. One of the Pennsylvania Railroad's achievements was the electrification of its main and many subsidiary lines between Philadelphia, New York, Harrisburg and Washington, D. C., making it necessary to lay hundreds of miles of new heavy tracks, capable of carrying a complete electric ground circuit and the weight of the electric locomotives. Many electric substations had to be built along the right of way to boost the electric current. A costly wiring system (called a catenary system) capable of carrying 11,000 volts and 132,000 volts had to be strung.

The new system of train operation made it necessary to educate railroad employees, including officials, enginemen, firemen, and engine house mechanics. In addition, every employee who had to work near or around electric sections of the railroad also had to be instructed in safety measures.

Taking everything into consideration (cost of engines at $250,000 each, wiring, trackage, employee education, etc.) it cost the railroad about one million dollars per mile of road for this conversion.

High capital investment costs limit electrification to sections of the system where special conditions exist. On other segments of the system, steam engines were used until the diesel came into the program. Since then, thousands of diesel electric locomotives have been purchased by the railroads, costing the companies tremendous sums of money.

Quoting from a press release (December 12, 1952) from the Pennsylvania Railroad for the information of the public:

"With delivery this week of the last road diesel locomotives in its current program, the Pennsylvania Railroad becomes the largest owner of diesel power as well as the largest owner of electric locomotives in the country, operating 96.4% of its passenger service and 81.8% of its freight service with these two types of motive power.

"In announcing receipt of the last four road locomotives in its $311,791,000 dieselization program, Pennsylvania officials said the road now has 316 locomotives of this type in service. The Pennsylvania operates 2,553,770 horsepower in diesel locomotives, along with 1,274,987 horsepower, on a comparable basis, in 269 electric locomotives, making a total of 3,828,757 horsepower in diesel and electric motive power.

"Fourteen diesel switchers were also delivered recently, bringing the number in service to 987, with 45 more to be received this month and in March. This will complete the current dieselization program with 1,348 engines in operation. When all the switchers are received, 91.1% of road and yard switching service will be by diesel or electric power.

"The locomotives now being delivered are among the 11 passenger, 4 freight and 165 switching engines ordered a year ago as part of the Pennsylvania's $651,397,000 over-all equipment improvement program which has been under way since World War II and is now nearing completion."

To work with cities and towns where it is necessary to use steam locomotives, men were picked and sent all over the United States to study and apply methods of abating smoke on coal-fired locomotives. Through this study, a locomotive smoke abatement device was designed and tested by the Pennsylvania Railroad. To equip the first locomotive, the cost to the Railroad was thousands of dollars. After satisfactory performance, the same equipment was installed on all steam shifting locomotives at a cost of $350.00 per locomotive. Further study developed a different type, the overfire steam jet, which was found to do a better job in abating smoke. The new type was then installed on all shifting locomotives.

The Pennsylvania Railroad continues to educate its employees. New firemen or others who will be working with fires are given on the day they are hired a copy of the smoke ordinance of the city in which they work, which is explained page by page, particularly his part in air pollution control. He also attends a school for 4 years and is thoroughly examined to determine his ability to pass the course of studies.

To control or conquer the "Phantom," we who bear the responsibility must have air pollution control at heart and we must constantly endeavor to improve our past performance.

Air Control and Research Program of the Kaiser Steel Corporation

J. H. Smith and G. L. Rounds
Kaiser Steel Corporation
Fontana, California

Eleven years ago, there was no legislation in California pertaining to air pollution; in fact, there was very little legislation of this nature any place in the world. Nevertheless, the Kaiser Steel Corporation at that time included in the original design of the Fontana plant all practicable air pollution control equipment and procedures. For example, our sinter plant stack is 300 ft. tall. It was originally intended to be 400 ft. tall, but the Civil Aeronautics Administration limited it to 300 ft. Our open hearth stacks were built higher than was customary to gain better dispersion of the effluents. The blast furnace was equipped with a system consisting of a dust catcher, a gas washer and a Cottrell precipitator. The coke ovens were equipped with self-sealing doors and a rigid "practice" was established to insure their working to their greatest efficiency. Coke-oven gas, used as fuel, was de-sulfurized. Baghouses and dust catchers were designed into the raw materials system. The railroad was dieselized.

Prior to 1950, air control work was performed by many departments. It then became obvious that air pollution was rapidly becoming a highly specialized and complex field. Therefore, our management created a Fume Investigation Unit as a part of the Metallurgical Department. In 1952, this unit was separated from the Metallurgical Department and expanded to create our present Air Control and Research Department. The department has its own office area and specially designed laboratory (Fig. 1). At the present time, a staff of 17 are working full time on air control problems. A number of authorities from different fields are retained to assist the group in the development of new projects; in the evaluation of collected data; in the designing of new equipment or techniques; or to perform in some particular capacity in which our personnel would not be considered sufficiently competent, e.g., the hiring of a meteorologist to plot surface wind patterns of the area.

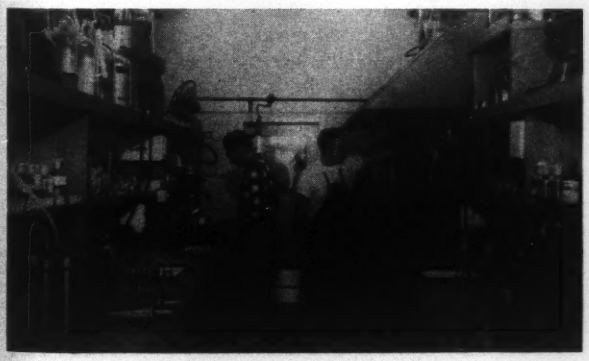


Fig. 1. View of Air Control Laboratory.

Major Projects

Open Hearth

We have 59 stacks within our plant limits. Most of them have been controlled for years. However, a few still present problems, and of these the open hearth stacks have been given priority. Last year in Baltimore we reported on some of the problems encountered in sampling from open hearth stacks. Here we wish to note certain chemical and physical changes which occur in open hearth effluents before collection or discharge.

The first indication of chemical change within the system was the emission of hematite from the top of an open hearth stack while magnetite was found at the stack sampling position. At that time, the furnace did not have a waste heat boiler. In this case, the conversion to the higher oxide of iron occurred somewhere between the 100 ft. level in the stack and the exit at the 175 ft. level. When the waste heat boiler was installed, this conversion occurred within the last section of the boiler. These facts pointed toward a temperature function. To further substantiate this theory, thermodynamic calculations were made for numerous chemical reactions which might occur in the regenerative system. The reactants and products of these reactions were both solids and gases. Studying the equilibria, we found that, under the conditions within the regenerative system, the reaction involving oxidation of ferrous oxide had a negative free energy; and further, that the value became more negative as the temperature lowered. Thus, this reaction could occur immediately after the checkers, although it is more apt to occur as the gases and solids cool on their way up the stack. Without a boiler, the oxidation did not occur until just before the gases made their exit from the top of the stack.

We should note also the conversion of fluorides from the gaseous to the solid state with decreasing temperature. Samples were taken from two locations in the system, namely at the exit of the waste heat boiler and at the 100 ft. level in the stack. An almost constant two-fold decrease in the percentage of gaseous fluoride was found as the effluent traveled 100 ft. in the system and decreased approximately 60°F. in temperature.

Of course, these phenomena may be ignored if one is interested only in the particulate matter which is emitted from an open hearth stack. The cited reactions are of interest, however, as examples of the chemical and physical changes which occur in effluents from the open hearth before they are collected or discharged to the atmosphere.

Vegetation Sampling

Our agricultural personnel gather leaf samples each month from 79 sampling stations within an area in excess of 1600 mi². In addition to the regular samples, our personnel periodically sample certain established "indicator" plants. The samples are then brought into the laboratory for chemical analysis.

A fumigation project has been initiated, consisting of an open plot and three greenhouses. It is hoped that the open plot will reveal the effects of the normal atmosphere on the test plants. The first greenhouse will have "unfiltered" or normal air circulated through it, revealing the effect of the greenhouse by comparing the test plants in it with those of the open plot. The second greenhouse is identical to the first, except that the air circulated is filtered through "Pliotron" filters and a bed of activated carbon. This greenhouse will reveal the effect on the test plants of an atmosphere which has had particulate and certain gaseous materials removed. The third greenhouse is identical to the second except that certain suspected air pollutants will be introduced into the air stream. The concentration of the fumigants used will be of the same magnitude that exists in the local atmosphere, if possible. Again, the test plants in the "fumigated" greenhouse will be compared with those in the first and second greenhouses.

In the very near future, another fumigation project will be initiated, wherein certain plants will be placed in fumigation chambers and exposed to suspected air pollutants, using concentrations ranging from 1 to 100 ppm.

An outstanding plant pathologist and a citrus authority

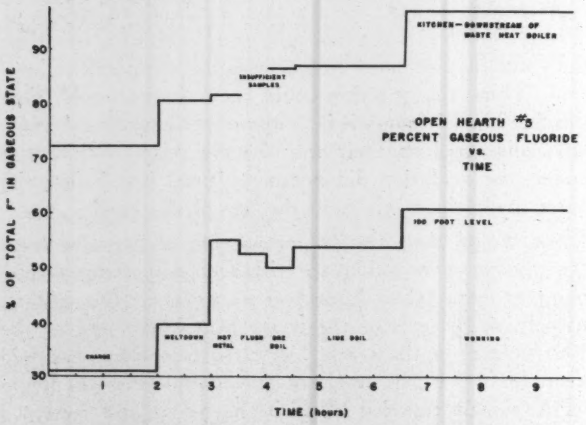


Fig. 2. Graph Showing Conversion of Fluoride Gas to Solid.

Fig. 3. Greenhouses.

are retained as consultants to assist in development of the agricultural program and also to make monthly surveys of vegetation in the area.

Three Thomas continuous autometers are maintained off the plant site to record SO_2 concentrations in the atmosphere. A fourth autometer is included in our mobile laboratory equipment and is used to obtain SO_2 concentrations throughout the area.

There is a very definite purpose behind our vegetation program. We feel that our effluents must be controlled to such degree that vegetation in the area will not be adversely affected. Legislation can stipulate that certain standards be met. However, since those standards are usually arbitrary in nature (perhaps unavoidably so, and are not always based on scientific data) we feel that it would be unwise to spend several million dollars attaining a given degree of control only to find, at a later date, that the standard was erroneous. We further believe that our vegetation program will permit us to isolate our mill effluents from those air pollutants or "smog" in the local atmosphere. This approach will permit us to establish definite control figures not only for our entire plant, but also for each operation therein.

Minor Projects

Paint Panel Boards

A number of red cedar panels are coated with paints of known composition and placed at critical points throughout the area. These paints react with characteristic changes when exposed to certain gases. The changes are measurable by light reflectance.

Dust Jars

18 dust jars are located within the plant area. These stations were stategically located for particular stack emissions through use of Sutton's equation for maximum ground concentration. Collection is made in jars containing distilled water. The jars are placed in specially designed boxes to keep air turbulence and radiant heat at a minimum. The samples are collected monthly and analyzed for:

1. Total dust fall: lb./1000 ft.²
2. Water soluble solids: as % total dust fall.
3. Water insoluble solids: as % total dust fall.
4. Loss on ignition of water soluble solids: as % total dust fall.

5. Ash, water solubles: as % total dust fall.
6. Certain inorganic compounds (Fe_2O_3, CaO, SiO_2, etc.)

Co-operative Weather Bureau

Another part of our program is the compiling of meteorological data. Kaiser Steel Corporation acts as a co-operative observer for the U. S. Weather Bureau. In addition to the usual maximum and minimum temperatures and rain gage data, we record wind velocity and wind direction, relative humidity, and barometric pressure in the area. This information is very helpful in planning further air control projects as well as in the interpretation of data obtained in the field.

Metallic Zinc Dust

We have encountered considerable difficulty in attempting to recover metallic zinc dust emitted from our pipe galvanizing department. The actual collection of the dust is quite simple; however, the explosibility and combustibility of the dust presents a problem as yet unsolved. The heavy dust is not a significant air pollutant, due to its rapid fall-out rate. Recovery is justified because of the value of the dust.

Mobile Laboratory

A panel truck has been converted into a mobile laboratory to assist in field work. Proposed work comprises the tracing of stack effluents, the recording of certain gaseous concentrations existing in the area, the determination of particulate matter found in the local atmosphere, and various other projects involving the use of a mobile laboratory.

Particle Size Determination

Our personnel are not satisfied with the methods currently being used to determine particle size. As a result considerable research is being conducted in an attempt to develop a fast, reliable method for our use. Over 70 members of the Air Pollution Control Association were contacted recently regarding this matter and it appears that the majority were likewise dissatisfied with present methods. Perhaps this is a suitable project for one of the A.P.C.A. committees.

Filter Media

There seems to be considerable controversy over the ability of activated carbon to adsorb certain gases occurring in the southern California atmosphere. Activated carbon was originally used in air-cleaning work to remove various identified contaminants. These contaminants were usually gaseous organic substances having large molecular dimensions. We, however, are faced with the problem of removing gases having small molecular dimensions.

Several tests were conducted in an effort to ascertain the efficiency of activated carbon in hydrogen fluoride removal. The results were not consistent; however, they did indicate an efficiency of adsorption between 80 and 98% with an inlet of approximately 0.5 ppm. of fluoride. The efficiency appeared to be an inverse function of the inlet concentration.

As a result of these preliminary tests, we are continuing to test various other materials in an effort to find an economical adsorption medium, or combination of same, which will remove most of the objectionable gases discharged by our plant.

Public Relations

While not a function of the Air Control and Research Department, we feel that it is imperative that a good

(Continued on page 209)

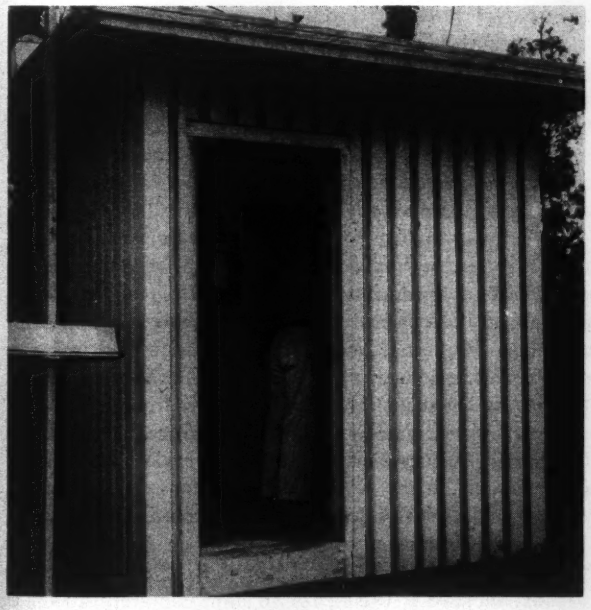


Fig. 4. SO_3 Station.

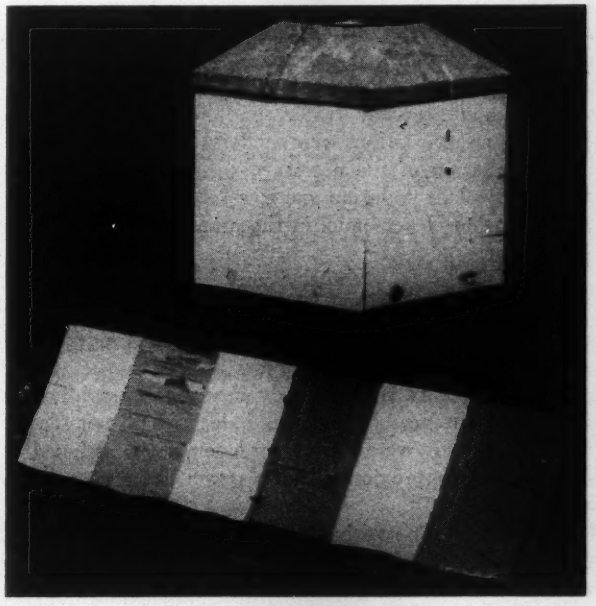


Fig. 5. Paint Panel Board and Dust Jar.

Air Pollution Control As in Effect on the Canadian National Railways

C. R. Patterson
Canadian National Railways
Toronto, Canada

In Canada, matters of air pollution control in the railway industry come under the jurisdiction of the Board of Transport Commissioners. This is a Federal Government agency, similar in jurisdiction to that of the Interstate Commerce Commission in the United States. In addition, each city and town may pass its own municipal ordinance governing those industrial operations which are the causes of air pollution. Personnel of the railway industry must be familiar with all regulations in order to operate equipment without violations.

As we review our performance of the past few years, I am amazed at the progress that has been made through the efforts of this Association and those who are equally determined to make our cities and towns cleaner and healthier places in which to live. The railroads have kept astride with other industries in controlling air pollution.

Due to the vast network of railway yards and roundhouse terminals extending from coast to coast on the Canadian National System, our problem in respect to controlling air pollution was by no means a simple one. To illustrate my point on the magnitude of this problem, at the peak of the Canadian National steam power era we had approximately 2,700 steam locomotives in service. Presently, after placing 500 Diesel units in service, we still have approximately 2,400 steam locomotives in service. In order to attack this problem systematically, and because of its prime importance, top management took the initiative in establishing an organization capable of coping with the problem, which, due to the increased volume of wartime and post-war traffic, had become very acute. Financial appropriations were made to cover the purchase and installation of the necessary equipment to satisfactorily control air pollution and to establish supervision for the education of personnel in the proper handling of this equipment.

Supervision

On the Canadian National System, our two most troublesome points of operation from the standpoint of air pollution control are Toronto and Montreal, where traffic movements are extremely heavy and roundhouses are located in heavily populated districts. During peak operations, there were 280 steam locomotives assigned at Toronto and approximately 240 steam engines at Montreal.

In order to cope with the problem at these terminals, 3 full-time smoke supervisors were appointed at Montreal and 2 at Toronto. These men were chosen from the ranks of locomotive firemen and they were carefully selected for their ability to grasp and put into effect practices pertaining to smoke abatement. Consideration was also given to their aggressiveness, their willingness to accept responsibility and their suitability for promotion to supervisory positions of more importance. These men continually police the terminals, frequently accompanied by city officials, to ensure that our railways fully observe the air pollution bylaws that are presently in effect. In addition, every motive power officer takes an active part in enforcing smoke regulations.

Enforcing Smoke Abatement Regulations

To enforce a program of this kind, disciplinary action can be taken by supervisory officers against those employees who wantonly disregard company regulations. In most instances, suitable instructions and warnings by the supervisory officer are sufficient. In the exceptional case of an employee who will not cooperate, after a warning has failed to have the desired effect a statement is taken of the violation and 5 demerit marks are assessed against his record. For subsequent offences, the disciplinary action is doubled. We consider that the locomotive engineer has direct jurisdiction over the fireman and unless it can be established that the fireman was not carrying out the engineer's instructions, the engineer is held equally responsible.

Firebuilders

After extensive studies were made of building and cleaning fires, nearly all our main terminals were equipped with an oil steaming-up system. This system utilizes Bunker "C" fuel oil and consists of a storage tank and oil circulating lines extending around the shop and returning to the originating point. Drop leads from these lines are coupled to air and oil hose of sufficient length so that when coupled in turn to a steaming-up burner, it will extend into the firebox door of an engine standing on the pit. The burner consists of two ½-inch pipes, one oil and one air, individually valved, leading to an atomizing chamber. The outlet end of the atomizing chamber is slotted and it is surrounded by a suitable hood to protect against overheating. The oil is pumped from the storage tank at approximately 180°F. and is forced through the line under pressure. Air pressure is approximately 100 lb./in.^{2}

Methods of Steaming and Firebuilding

To use this burner to best advantage, line the grates with a horseshoe bank of coal 8 in. deep at the front of the firebox, increasing the depth to approximately 20 in. at

(Continued on page 218)

Technical Aspects of High Temperature Gas Cleaning for Steel Making Processes*

Leslie Silverman
Harvard University
School of Public Health

The problem of controlling gaseous and particulate effluents from steelmaking processes is one which has concerned major steel producers in this country for several years. With increased plant capacity and under accelerated production there has been, of course, an increase in the amount of gaseous wastes, although improved processes in the industry have kept the rate of contaminant emanation from increasing at the same rate as steel production. The problem, of course, varies with the process involved and the economic and community aspects may therefore be quite complex. It is intended in this discussion to describe briefly the principal problems associated with each important process and to give some preliminary information with regard to a fundamental study which we have undertaken at Harvard with the support of the American Iron and Steel Institute. On problems of this type all steel producers have a common meeting ground and are determined to make a joint effort for their solution through the Institute.

The problem of high temperature gas cleaning in general, regardless of whether it is associated with steel or ferro alloy processes, is one which is perhaps the most perplexing to industry in general. It is difficult because the problem is usually associated with extremely fine particles dispersed in gases at temperatures in the vicinity of 500 to 1500°F. In some instances even higher temperatures may be involved. Because of the fine aerosol and the high temperatures involved, the customary approaches do not usually solve the problem. Consequently, progress has not been as rapid as might appear possible to those unaware of these handicaps. Basic problems associated with high temperature gas cleaning are those of economics and fundamental requirements for cleaning. In some instances the cleaning of the waste gases is necessary because it represents a material of substantial value or, if the particulate material is removed, a gas remains which is combustible and is recovered in the form of heat or energy which can be utilized in the process. In other instances economic value of the effluent, either particulate, gaseous, or the usual combination, is of such small magnitude that the cost of disposal represents a sizeable problem. In these cases the cleaning or removal necessary to prevent air pollution is one for which there is only an intangible return. Unfortunately, the steel-making process, in general, results in contamination in the latter category. Therefore, the desire of the industry is to obtain cleaning at minimal cost without imposing a burden in the form of increased production costs. The cost of preventing community air pollution and possible injury to property or the public is usually without any tangible recovery other than good public relations. The industry in general is anxious to live in harmony with its neighbors and for that reason is supporting basic research such as our project at Harvard and other work in the general field of air pollution evaluation and control. Our particular project is a fundamental investigation of cleaning of air and gaseous contaminants, particularly those of fumes created by steel-making processes. Our program is directed initially toward a satisfactory solution of the open hearth furnace problem. If we are successful in arriving at a satisfactory solution the results can be applied to many other processes with modifications.

*Presented at the East Central Section Meeting of the Air Pollution Control Association at Youngstown, Ohio, September 23, 1954.

Based on studies performed under a contract between Harvard University and the American Iron and Steel Institute.

Sources of Air Pollution

In steel production there are 5 principal sources of pollution in terms of types of process equipment. I am not going to detail the various processes, inasmuch as I am not an authority on any one of the steel-making processes. Our interest for many years has been primarily on aerosol technology and air and gas cleaning. In particular, in recent years we have worked on the cleaning problems of atomic energy processes which have excessively high requirements as compared to any other industry.

The basic steel-making processes in terms of sources of pollution and operations which require some control are: (1) blast furnaces, (2) converters, (3) sintering plants, (4) open hearth furnaces, and (5) electric furnaces. All of these steel-making processes are related and in many large integrated plants all five types may be encountered. There are a number of other miscellaneous operations such as coke oven and power plants but it is not intended here to discuss anything but those operations which produce iron or steel in some form. The gaseous effluent from each of these operations varies and I shall discuss them briefly.

1. Blast Furnace

Blast furnaces account for a large proportion of the air volumes involved in steel manufacturing. The gas discharged from the furnaces contains large amounts of solid impurities, principally iron oxide, and a consider-

able amount of gas of recoverable heating value. In fact, it was observed quite early that the cleaning of blast furnace gas and recovery of the heating value of the gas could be put on a firm return basis. The gas has been cleaned by mechanical collectors, followed by wet types, and usually is given final treatment with electrostatic precipitators which remove almost all of the particulate matter. It should be recognized that particle loadings, in terms of gr./ft.^{3} of air, are highest for the blast furnace and cover the widest range of sizes, from particles of mesh sizes to submicron. By weight, most of the material is of a size which can be readily captured by centrifugal (above 5 μ) and scrubber type units (above 1 μ). The grain loadings range from 50 gr./ft.^{3} of air downward and the primary dust catcher is able to remove as much as 60 to 70% of the total dust. A secondary collector which is usually a scrubber unit of varying types will clean to about 0.1 to 0.7 gr., after which the Theissen Disintegrator or electrostatic precipitators will clean the gas to less than 0.001 gr./ft.^{3} The gas after cleaning can be used to heat the air blast, run engines or turbines, or for general heating purposes. Because of the need for very clean gas in these applications it is essential in most instances where the gas is to be re-used to reduce its loading to less than 0.001 gr./ft.^{3} The only major problem concerned with air pollution from blast furnaces when they are provided with adequate fume control equipment is the so-called "slip." A "slip" is created when the furnace burden shifts irregularly and a violent rush of gas to the piping system results. As a safety measure, these sudden gaseous loads are valved to the atmosphere, and this procedure causes a visible, heavily laden dust and fume cloud. Direct solution of the problem of slips does not exist at present except by careful furnace control. Extensive studies of this problem have been made and further instrumentation may be a solution to better control of the furnace. Major slips have been avoided by several blast furnace operators over long periods with very careful operation. Conditions similar to the blast furnace occur in furnaces producing ferro-manganese, and Bishop[1] has described this problem in a recent article. A complete pilot installation was operated for some time and on the basis of this pilot unit a full size collection system was installed and is now in operation.

2. Converter

The amount of steel made today in the U.S. by the Bessemer process is limited. Brandt[2] points out that at the Sparrows Point plant (Bethlehem) there are 3 converters which account for only 7% of the steel made at this plant. The converter problem has not been solved and it is not intended here to discuss its various ramifications. During World War II the Germans and English were able to provide glare shielding or ducting on converters. It is theoretically possible to clean any effluent which can be ducted if proper equipment is employed. In the case of the converter, however, it may be uneconomical and involved. Since this process is now falling into discard it would not appear on the surface to be worthy of concentrated effort until more pertinent problems are solved. The oxygen converter or the so-called Brassert process may revise our thinking about the cleaning of converter effluents in the near future. However, at the present time the fact remains that most American steel producers are eliminating the converter from their operations for technical reasons, as well as recognizing it is a difficult problem in air pollution control. Among air pollution sources in the industry, the converter is one of the worst and also the most difficult to control.

3. Sintering Plant

In blast furnace raw materials there is always a considerable amount of fines which present a nuisance from the operational standpoint as well as a difficult gas cleaning problem if not removed before the charging of the furnace. It is current practice to screen the fines from the materials for charging to the furnace and to put them through a sintering process in which the fines are converted to a very porous cake which can be placed in the blast furnace. There are two sources of air pollution in the sintering plant—one is the gas coming through the grate on which burning or sintering is conducted, where some of the fine materials are entrained and carried into the stack, and there is also a fair amount of contamination at the discharge end of the sinter belt where the hot sinter cake falls down a chute. At the present time, sintering plants have resorted to mechanical-type collectors, although Brandt[2] reports the installation of an electrostatic precipitator on the sintering plant at Sparrows Point. Small diameter cyclones may also be used on the discharge vent air and the material collected in mechanical collectors or cyclones can then be returned to the sintering operation for re-use. With the wide variety of ores now handled in various mills it is possible that the sintering operation may become a more aggravating problem; however, at the present time it does not involve as high temperatures as some of the other processes such as blast or open hearth furnaces.

4. Open Hearth Furnace

The open hearth furnace today represents one of the major sources of steel production in plant operations and there are approximately 1100 open hearth furnaces in this country, varying in size from small steel foundry units (10 to 20 tons) to larger ones of 400 to 500 ton capacity. The average steel mill hearth has a 250 ton capacity. In the steel industry, open hearth furnace fume control is considered one of its major unsolved problems.

Distinction is made between cold and hot metal furnaces. Operations in which metal scrap is charged and

(1) Bishop, C. A., "Cleaning Ferro-manganese Blast Furnace Gas", preprint of paper presented before General Meeting of American Iron and Steel Institute, New York, May 23, 24, 1951.

(2) Brandt, A. D., "Air Pollution Control in the Bethlehem Steel Company," *Iron and Steel Engineer*, August, 1954.

melted down are called cold metal types, whereas in the large mills where blast furnaces are available, hot metal as well as scrap may be charged directly into the open hearth. These are considerably larger in size and higher in production rate and are known as hot metal furnaces.

According to published reports, stack loadings may range as high as 2 gr./scf. of air momentarily but average concentrations in the stack are about 0.4 gr. Through various parts of the cycle, loadings may vary from less than 0.1 gr. to the maximum values. There is considerable variation in the open hearth furnace stack loading, depending upon the control of operations in the plant. Stack temperatures may range from 1100 to 1400°F. before the waste heat boilers and from 450 to 550°F. after waste heat boilers. The fume is primarily freshly formed iron oxide and ranges in size from less than 0.001 to several μ (larger particles resulting from agglomeration). The bulk of the material consists of iron oxide fume, 90% less than 5 μ by weight. There are two reports on particle size, one stating that about 50% by weight is smaller than 5 μ and the other that the mean particle diameter is 0.5 μ with no particles above 3 μ. In field work we have performed recently, we are inclined to confirm the latter figures; in fact, our mean size values are considerably below 0.5 μ on samples taken before the waste heat boiler. Composition varies throughout the cycle (which has several phases) and much less than 90% iron oxide is present during certain phases, particularly in the lime boil.

In terms of continued operation, open hearth stacks can create some loss in visibility in the general neighborhood at ground level. Most of the fume is of such a fine size, however, as to drift for several miles as a highly visible plume before dispersion and settling has taken place. By number, most of the particles are below 0.1 μ, which in terms of light scattering as a cloud is tremendous. Because of the large number of installations of open hearth furnaces operating in this country in several major cities in which pollution control is becoming more stringent, the steel industry felt that this is one of its important pollution problems and should be solved first. The problem is especially difficult because of the fineness of the fume and the high temperature of the effluent gases. Even after waste heat boilers, the temperatures are still at values to which most present collectors cannot be adapted without special handling or cooling techniques. 2 principal types of collectors can clean open hearth gases effectively (90% or higher removal by weight) although many others have been tried. It will suffice to mention here that only 3 types of collectors have given satisfactory removal in pilot installations, namely, the Venturi scrubber, cloth bag filter with orlon fabric, and the electrostatic precipitator. Only the latter has been applied to a very limited number of full size installations with reasonable success.

In pilot installations where bag filters and electrostatic precipitators have been utilized and in full scale precipitators it has been found necessary to humidify and condition the gases. For the fabric collector using synthetic or glass fabrics, a cooling tower or enough dilution air is necessary to drop the temperature of the gases to a safe value. In the case of the electrostatic precipitator, conditioning is necessary to overcome some of the problems in collection resulting from the increased resistivity of the deposit as discussed below in detail.

5. Electric Furnaces

The electric furnace presents a problem similar to the open hearth except that the units in general are not so large. The fume is of comparable size and iron composition but loadings are considerably lower.[3] It is our opinion that the electric furnace presents problems in fume size and temperature of a nature directly comparable to the open hearth. In the case of the electric furnace, however, hooding problems may be more complex.[2] The use of open hoods results in temperatures low enough for direct application of bag filter units.[4]

Cleaning Requirements and Present Methods of Hot Gas Cleaning

Requirements for cleaning effluent gases from all processes (as well as steel making) are well defined in locations such as Allegheny County and Los Angeles. These requirements are designed to meet the needs and conditions of the general community. For the blast furnace, the problem is largely one of eliminating slips since most blast furnaces in steel plants are equipped with multistage cleaning devices as outlined above. In the case of converter, sintering plant and furnace discharges, loadings must correspond to limiting emission values per ft.^{3} of stack gas volume. In various codes these range from 0.3 gr./ft.^{3} of gas to values as high as 0.75 gr. In Los Angeles, however, emission is based on a weight of charge to the process, with an upper value beyond which further emission is prohibited. The same values are generally applied to open hearth and electric furnace stacks at the present time. Pressure to provide cleaning for open hearth stacks prevails only in congested communities where the stacks appear to obscure visibility and in general produce nuisance complaints.

Cleaning requirements for the open hearth stack depend on the loading and the question of whether or not a visible plume must be eliminated. We feel that if no settling takes place and the plume is diluted to an imperceptible amount at ground level the cleaning should be considered adequate. The following calculations will indicate orders of magnitude. If we assume an average loading in the stack of 0.4 gr./ft.^{3} and the point at which

(2) See footnote (2) page 190.

(3) Allen, G. L., Viets, F. H., and McCabe, L. C., "Control of Metallurgical and Mineral Dusts and Fumes in Los Angeles County, Calif.," U.S. Bur. Mines, *Information Circular 7627*, April, 1952.

(4) Erickson, O. E., "Electric Steel Foundries Control Dust Emissions in Los Angeles Area", *Journal of Metals*, December, 1953.

visibility of the plume disappears at 0.05 gr./ft.^{3} or less, then a value of approximately 90% efficiency by weight would appear to be satisfactory. We have made calculations of particle numbers, assuming a mean fume size of 0.4 μ and a loading of 1 gr./ft.^{3}, wherein each ft.^{3} would contain approximately 75 x 10^{10} particles. Because air in metropolitan communities contains about 5 x 10^6 particles in this size range, it can be seen that 15 x 10^4 dilution would be necessary to provide an absolutely invisible stack. Fortunately, at least 10^3 to 10^4 dilution takes place in the descending and diluting stack plume by meteorologic dispersion; hence, it is apparent that a cleaning efficiency of 95% (1.20 dilution) can take care of most stack effluents. This is a generalization, however, and there may be conditions which vary enough in character for special handling. Kayse[5] in a recent article contends that a visible effluent is a value of 0.005 gr./ft.^{3} This is 0.1 the value given above and would require phenomenal control. The character of the fume from even similar processes (such as the open hearth) is variable because of the variations in raw materials, fuels and operations. Thus the visibility of the fume will vary with operations from a similar process. Visibility is highly dependent upon particle size since light scattering of small particles less than 0.5 μ is an exponential function where n may approach values of 7; consequently, any generalization should be avoided.

In terms of available power consumption and permissible resistance which can be inserted into the stack, we have been informed that the limiting value of resistance for any cleaner should be about 4 in. of water. In summary, the present need for open hearth or electric furnaces is a cleaning unit which removes 90 to 95% of the fume at resistances not exceeding 4 in. of water. These are 2 of the aims of our study on open hearth gas cleaning.

It should be emphasized also that unlike the blast furnace, fume recovered from the open hearth, although high in iron content, also contains what may be objectionable amounts of sulfur. Because of the low grain loading, an average size open hearth furnace (25,000 scfm.) at a loading of 0.4 gr./ft.^{3}, 100% efficient collection would recover approximately one ton per 24 hr. A good estimating range is from 4 to 10 lb. of fume per ton of steel produced (average 7 lb.) to obtain fume recovery values. The value of this material is estimated at approximately $15.00 per ton with an obviously difficult handling problem, even if delivered at the sintering plant. It is apparent that the product recovered will not be a significant factor in off-setting operating costs and may even add an additional nuisance problem.

Cleaning, therefore, must be at absolute minimal cost without interposing excessive disposal costs and problems. If we assume the production cost of steel for calculating purposes at $50.00 per ton, and the power costs at 0.5 mils per kwh., the cost of operating a cleaner at 4 in. resistance and 25,000 cfm., using a 63% combination blower and motor efficiency can be readily calculated. In this case, 25 hp. or 18.3 kw. is involved ($0.092 per hour or $2.23 per day) as a direct cost without overhead or fixed charges. Air moving for the electrostatic precipitator at ½ inch of water pressure loss would be ⅛ of this cost for an installed blower, although natural draft may be adequate in some cases. Resistances of baghouses would be in the 4 in. range calculated above. Assuming a 250 ton furnace and 3 heats per day, the amount of steel is 750 tons or $37,500. If the maintenance, depreciation, power, and disposal costs can be kept in the range of 0.2 to 0.4% of production costs ($75.00 to $150.00 per day) it will probably be acceptable to management. This is another important factor to be considered in the open hearth cleaning problem.

Location of Cleaner

It would be desirable to have gases cleaned before the waste heat boiler in the open hearth furnace for several reasons. The most important would be the improvement in heat recovery at the boiler, and reduced cleaning and maintenance frequency schedules for the waste heat boiler. In considering the over-all problem of cleaning hot gases, one must recognize that there are other advantages and disadvantages of cleaning before any heat recovery equipment but, on the other hand, there are some advantages and disadvantages to cleaning after heat recovery equipment. In terms of advantages of cleaning before heat recovery equipment, the first and most obvious one is that if cleaning could be done at temperatures of 1000°F. or more it would be possible to eliminate waste heat boilers if steam production was not needed. From basic economics this does not appear sound on an operating basis, since the energy available between 500° and 1000°F. with the gas volumes involved is important and can result in substantial economic recovery. The capital cost of the waste heat boiler, however, may offset this advantage. In one situation to our knowledge, adequate steam is already available and the cost of the waste heat boiler (a substantial item) would therefore be charged to the cleaning equipment which may require it. Consequently, for this operation, if adequate cleaning could be done without a boiler, it would be the method of choice. The second advantage of cleaning directly at high temperatures is that it minimizes fume deposition on heat recovery surfaces and thus provides improved heat transfer and reduced maintenance and cleaning problems. It is customary in waste heat boiler operation on open hearth stacks to permit fume deposition until a certain flow resistance is reached, at which time the tubes are blown. It is obvious that if this could be circumvented the power consumption of the blower could be kept at a lower value, since the resistance across the waste heat boiler would not increase rapidly. Assuming that the installed cleaner before a boiler had 90% efficiency, then the down time for clean-

(5) Kayse, J. R., "Graphical Selector for Air Cleaners", *Heating and Ventilating, 50,* 80 (1953).

ing could theoretically be reduced to 10% of present values. There is also an added advantage in that the duct work following the cleaner would remain cleaner for longer periods.

The disadvantages of cleaning before the waste heat boiler or at high temperatures (above 600°F.) are fairly obvious. Higher temperature materials for the cleaning unit are needed, and in many cases this becomes almost insurmountable; and another disadvantage which has developed in our work on filtration using refractory filter media is that the elevated temperature means increased viscosity of gas (streamline flow range) and consequently much higher resistances. Increased temperature also means decreased gas density with a consequent reduction in blower performance. Its effect on precipitator operation has already been covered.

Advantages to cleaning after the heat recovery equipment or waste heat boiler are the converse of many of the above disadvantages. Obviously, lower gas volumes are involved, which reduce velocities and viscosity and hence the resistance. A reduction of temperature between 500° and 1000°F. involves nearly a 50% reduction in air volume. The waste heat boiler presumably is also an agglomerator and reduces stack loading because of collection on the extended surfaces. The agglomerating effect of the extended surface is to produce a larger size particle by re-entrainment which may be easier to capture by inertial or filtration procedures. Blower performance is improved and corrosion and temperature resistant materials which are necessary are readily available and less expensive. Size and costs of the air moving equipment are therefore reduced.

The disadvantages of cleaning after the waste heat boiler are opposed to the advantages cited, e.g., heat transfer is not as good and the cost of auxiliary equipment for cooling, such as the waste heat boiler, air-to-air heat exchangers, spray towers, or use of air dilution, all must be accounted for in the over-all capital outlay for cleaning.

Type of Cleaner

Inertial Cleaner

In the early part of this paper a point was made that the cleaning of high temperature gases is a relatively virgin field, since very little has been accomplished in this regard. When the problem includes not only high temperatures but also extremely fine particles such as are produced by vaporized iron, then the problem is doubly difficult. In the case of removing coarse particles from hot gases, methods which have been used in power plants for fly ash and in blast furnaces for primary cleaning (namely, the inertial or the centrifugal collector) have been the method of choice and will continue to be so. Tests have been made on open hearth furnaces with devices of this type. In particular, a recent study by Vajda[6] has shown that with actual open hearth furnace fume the recovery is less than 50%. This is obviously not satisfactory in terms of eliminating the nuisance or minimizing the community problem.

Wet Cleaners

In addition to the inertial collector which can withstand the high temperatures involved but does not remove material below 5 μ, the next units in terms of possible application are wet devices such as the impingement type, the Venturi or high pressure fog-nozzle hydraulic scrubber. All of these simpler types have been tried in pilot studies and some results are shown by Vajda[6]. However, they also fail to meet the requirements given above. The Venturi scrubber has been reported by Jones[7] to give values that were satisfactory in terms of cleaning performance but the resistance, power consumption, erosion, and waste disposal which resulted made application of this device unsuitable, according to many plant operators. It must be recognized that any wet collector which has the advantage of cooling the gases rapidly will also absorb a considerable amount of sulfur gases with acid formation. Consequently, there is a distinct value from the corrosion standpoint as well as cost of water disposal, etc., in being able to clean the gas dry.

Filtration Units

The next type of collector which has been applied to the problem but only on a pilot scale in the steel industry (although used in large installations in the nonferrous industry) is the fabric collector utilizing cloth bags or tubes. Results of a large, pilot-scale study have been recently reported by Pring[8] with satisfactory results. The chief limitations to this device are that auxiliary cooling is necessary to bring the gas temperature to within that of the limits of the bag materials, namely 200°F. for wool and 275°F. for orlon type fabrics, and the cooling must be well controlled in order to provide gases which will not condense on the bag surfaces. The tests reported by Pring show very satisfactory efficiencies and low resistances but (since these are accomplished at filtration velocities on the order of 2-3 fpm.) the size of the equipment for typical open hearth furnaces, or even a number of furnaces operating through a central unit, results in large structures and facilities. Consequently, open hearth operators have been reluctant to adopt this equipment because of space limitations and the fact that cooling equipment and controls are needed. Because of the high temperatures involved, there must be interlocking safety devices if such equipment is used in order to prevent excessive temperatures from damaging the bag materials. It is also necessary to supply water for cooling even after the waste heat boiler cools the gases to 500°F. before they enter the spray tower used in conjunction with the bag collector. A spray tower could take care of all cooling, however, if desired. The proposed cost of this equipment as reported by Pring

(6) Vajda, S., "Open Hearth Dust Control". *Iron and Steel Engineer Yearbook*, 1952.

(7) Jones, W. P., "Development of the Venturi Scrubber", *Industrial and Engineering Chemistry, 41*, 2424 (1949).

(8) Pring, R. T., "Filtration of Hot Gases", *Air Repair 4*, 40 (1954).

for a large multiple furnace installation is about three-quarters that for precipitators, but there have been no installations made which would indicate operation costs, maintenance and other problems. The installation of bag units on electric furnaces and cupolas have been thoroughly satisfactory except from a space standpoint.

Improvements in fabrics, such as abrasion resistant glass or asbestos when developed, may change the present picture.

Pebble filters have been tried on a pilot scale as reported by Vajda[6] with no outstanding performance. It is contrary to theory and experience to use large collecting surfaces, as will be shown later, since both impaction and diffusion separation[9] call for small diameter (micron size) targets for efficient removal.

Electrostatic Precipitators

The electrostatic precipitator to date has been the method of choice for the open hearth and the electric furnace. It has not been a choice without difficulties, however, because of the variety of problems each application has encountered.

Electrostatic precipitators have been installed on several open hearth furnaces at the new Fairless Works of U. S. Steel Corp., and on one furnace at the Fontana plant of Kaiser Steel Co. A few cold metal and several electric furnaces have also installed units. It was found necessary to condition the gas in all cases because of the nature of the iron oxide fume collected. Conditioning means insertion of a considerable amount of spray water into the gas stream and this too has created corrosion and other problems.

In discussing the application of electrostatic precipitators to high temperature gases it must first be recognized that these devices will not work at temperatures exceeding 500°F. without some treatment of the gas stream. The difficulties with high temperatures are (1) the gas has low dielectric strength and therefore arcing becomes a problem, (2) insulator materials which will withstand high temperatures are limited and no satisfactory ones have been developed to-date for long life at temperatures above 600°F., and (3) at temperatures of 300 to 700°F. the resistivity of the deposit goes through its highest values (as shown by Sproull and Nakada[10]) and it is thus necessary to condition the deposit to prevent excessive voltage loss at the collecting surface. Were it possible to obtain high temperature insulator materials it would be possible to be working on the other side of the curve but this has not been done yet. In the low temperature range, it appears that temperatures not exceeding 350-400°F. will give satisfactory operation if the plates can be cleaned at frequent intervals and if the gas is conditioned.

One difficulty in the use of electrostatic precipitators on open hearth and electric furnaces is the fact that the resistivity and adhesive nature of the fume deposited on the plate surfaces varies in character with the raw materials. Consequently, each installation may require some pilot investigation before it can operate with certainty.

Operating performance of the precipitator has indicated that with proper voltages (40 to 60 kv.) efficiencies ranging from 85 to 95% are possible at resistances on the order of ½ in. of water. It is apparent that the electrostatic precipitator can be adapted to the problem. At the present time, application is limited because of excessively high costs. It is necessary to provide waste heat boilers for precipitator applications, since they require this much and even further spray cooling. All of the cooling could conceivably be done with sprays, if desired. Secondly, the capital cost of the precipitator is on the order of $400,000 to $600,000 per furnace. Such costs are a sizeable fraction of the cost of a new furnace installation. With open hearth furnace costs in the range of $1,000,000, management is reluctant (unless able to obtain rapid amortization) to invest such large sums in electrostatic cleaning equipment.

This discussion is all an introduction to the chief reason the American Iron and Steel Institute is interested in research on developing new and improved methods for cleaning open hearth gases.

American Iron and Steel Institute Project at Harvard

In November 1953, the Subcommittee on Air Pollution Control of the American Iron and Steel Institute initiated a research program at Harvard on methods of controlling and removing effluent fumes resulting from open hearth steel manufacturing operations. This project had rather broad implications since it was hoped that fundamental research into the problem would lead to more economical methods for cleaning high temperature gases of fine particulate material. Our study has been along two basic lines, primarily with regard to the removal of fine fume comparable in size to vaporized iron from steel-making processes.

In setting up the program, the Subcommittee believed that work of a fundamental character could lead to a practical and reasonable cost solution of the problem. We were given a free hand as to the methods chosen for study and research programming. It was suggested that we could explore present methods with a view to improving them or initiate any new approach to the problem we desired. In our Atomic Energy air-cleaning program, investigation of radioactive aerosols has led to the development of high temperature and corrosion resistant filter materials (such as all-glass paper) which give performance far in excess of that necessary for the open hearth furnace requirements outlined above. However, these materials to date are adapted only to the extremely low grain loadings involved in radio-chemical work, where the life of such units is great at loadings corresponding to atmospheric air. The life

(6) See footnote (6) page 193.
(9) Silverman, L., "Performance of Industrial Aerosol Filters", *Chemical Engineering Progress*, *47*, 462 (1951).
(10) Sproull, W. T., and Nakada, Y., "Operation of Cottrell Precipitators. Effects of Moisture and Temperature", *Industrial and Engineering Chemistry*, *43*, 1350 (1951).

would be too limited to adapt to the open hearth furnace problem without considerable development of cleaning methods for such filters. It is important to note, however, that it is possible to produce a filter paper from fine glass fibers which will remove 99.98% of 0.3 μ particles.

It would be desirable, if possible, to clean at temperatures at least as high as 500°F. without cooling, although a filter medium or device which removes fine particulates satisfactorily at 500°F. is not available at the present time. We were not limited in our approach to any one particular aspect of cleaning mechanisms but felt that in view of our experience with filtration this was the most suitable direction. We have divided our fundamental investigation program into two major phases: first, the study of agglomeration devices or means of producing on-stream agglomeration; and second, development of filtration media or devices utilizing the filtration principle.

Work on the agglomeration approach is still in too premature a stage to report in detail here. We have concentrated our efforts in the past nine months in developing a suitable filtration approach to the problem, in the hope that if this were successful then any agglomeration device developed could increase filter life, since it would serve to aggregate and increase the resultant particle size of the aerosol.

In the search for a suitable filtration medium, consideration was given to the application of mineral wool fibers. Chemical warfare work on gas mask filters[11] has shown that commercial rock wool, which has a mean fiber size of approximately 4 μ, could be made into a satisfactory gas mask filter. It was intended that for strategic, civilian defense supply purposes this would be one of the basic materials considered, since it is available in large quantity at low cost.

The use of slag or rock wool has several important features from our standpoint. Basically, it is a fine, refractory fiber theoretically able to withstand elevated temperature (1000°F.); it is produced in bulk at low cost; and it is available at or near several steel mills, since it is readily made from by-product blast furnace slag. In fact, one of the steel mills in the east that we visited recently as part of our investigation has a slag-wool plant in operation, as do some other plants.

Before discussing our fundamental studies at any great length it is well to point out some of the principles of separation of aerosols by filters. In Table I are shown the principal mechanisms utilized in filter-fiber separation: direct interception, gravity, impaction, diffusion, electrostatic charge, and straining. Contrary to popular impression, straining is the least important of the fiber filter mechanisms. In filtering open hearth fume it must be recognized that (because of the fine particle size and low mass) direct interception and gravity cannot be significant forces. The most important forces, in our opinion, are impaction and diffusion, since they are both effective in the size range of open hearth fumes. Because of our desire to provide a filter with minimum cross-section and operating at high velocity (200 fpm.) to reduce space requirements, it was felt that diffusion might be helpful in agglomerating fume particles before the filter but not of too much importance in actual separation. Because of the increased mobility of particles at high temperature this would appear to increase diffusion effects, but increased viscosity is also a factor in reducing mobility. Straining, however, is a possible mechanism after a layer of aerosol accumulates on the filter surface. In the application of the bag-type filter mentioned earlier, this is the most important mechanism, since the deposited aerosol (because of its size) will leave very fine pores between the particles which form an effective filtration cake. Unfortunately, when straining takes place resistance increases quite rapidly, and the extent to which such a surface can be used requires low velocities and a large surface area (which leads to large space requirements). Electrostatic charge, of course, is not present because of the high temperature and the charge on such particles leak off immediately after formation. It is therefore indicated that in the filtration of high

TABLE I

Separating Mechanism and Parameters in Fiber Filtration of Aerosols

Mechanism	Description	Size Range Over Which Separation Is Most Effected (Microns)	Parameter
Direct Interception	Although any size may be separated it is not an important force, since it is limited to particles whose centers remain in coincidence with a streamline (becomes small when particles are small)	>1	Separation $= f\left(\frac{d}{D}\right)$ d = particle diameter D = fiber diameter
Gravity	Basically a function of particle mass, since it must settle on fibers in passing through	>1	Separation = f (Stokes' law and its corrections) Settling velocity $= f\left(\frac{gd^2\rho}{\mu}\right)$ g = gravitational constant μ = viscosity ρ = particle density
Impaction (Inertial Effect)	Due to particle mass and velocity. Change in direction in streamlines over fibers may cause particle to separate, since it may continue in original or altered path	>1	Separation = f (Impactibility) where $\frac{mV}{kD} = \frac{Vd^2}{18D\mu} = f\left(\frac{D\rho}{Vf}\right)$ = Impactibility where m = particle mass k = Stokes' law coefficient (for spheres = $3\pi\mu d$) d = particle diameter D = fiber diameter V = velocity f = free falling velocity of particle
Diffusion	Separation is due to random molecular movement of particles (Brownian motion)	<0.01-0.5	Separation $= f\left(\frac{1}{\frac{\mu}{d}DV}\right)$ Units as defined above
Electrostatic Forces	Separation is a function of charge on particle and charge on collecting fiber. There are 3 cases: I. Uncharged fiber-charged particle II. Uncharged particle-charged fiber III. Charged particle-charged fiber	<0.01-5	Separation = f (3 forces, namely: coulombic, dielectrophoretic and image forces); Important factors: particle charge q_p; fiber charge q_f; distance of particle from fiber; particle diameter and field strength. In high electrostatic fields, charge on particle becomes less important relatively.
Straining	Separation is due to pure screening of particles because of their inability to pass through a smaller opening	$>$ filter pore or void size. (Voids formed by deposited aerosol layer)	Separation = f (d, particle shape, porosity of filter, porosity of deposited aerosol layer)
MISCELLANEOUS OTHER FORCES			
Thermal	Separation due to difference in temperature between particle and fiber	<0.01-5	Separation = f (Δt, distance, velocity)
Magnetic	Separation due to magnetic field	<0.01-5	Separation = f (magnetic field strength, particle composition, velocity)

(11) Rodebush, W. H., "Filtration of Aerosols", Chapter 9, "Handbook on Aerosols", U.S. Atomic Energy Commission, Washington, D.C., 1950.

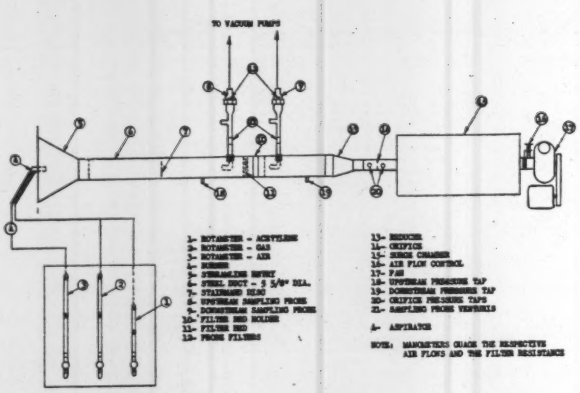


Fig. 1. Arrangement of Test Apparatus for Determining Resistance, Efficiency and Life of Slag-Wool Filters.

temperature gas, application of a fibrous media such as slag wool would depend principally upon impaction, diffusion, and some straining.

A filter that is satisfactory for open hearth or high temperature furnaces in general, we believe, must operate at velocities comparable to air conditioning filters (100 to 300 fpm.) Several years ago steel wool was tried on the blast furnace by Kling and Weidlein[12], their method involving vibrating or rapping the filter to remove the deposited cake. This was not too successful, notwithstanding the large particles involved. In our case we felt that velocities which could be tolerated, in terms of space available adjacent to the open hearth furnace, would have to be such that the cross-section area of the collector would not be much greater than electrostatic precipitators. Accordingly, all of our investigations have been made at velocities of 100 to 250 fpm. For a 50,000 cfm. (at 500°F.) open hearth furnace stack, it is apparent that the cross-sectional area for a filter would only have to be 250 ft.^{2} at a mean face velocity of 200 fpm.

(12) Kling-Weidlein Dry Gas Cleaner, see Marks, L. S., "Mechanical Engineers Handbook", 3rd Edition, McGraw-Hill Book Company, New York, 1930 (p. 813).

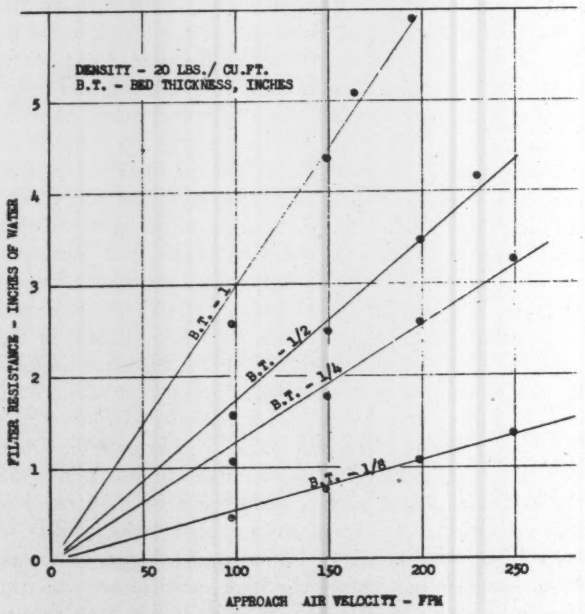


Fig. 2(a). Resistance Characteristics of Slag-Wool Filters at Constant Density, Varying Thickness.

Experimental Program at Harvard

The problem of determining the effectiveness of slag wool as a refractory filter is essentially one of testing layers of known density and thickness at temperatures and with loadings of iron fume of a size comparable to open hearth stack effluents. The fume was generated by passing flake iron powder (mean size 4 μ) through the air side of an air-oxygen-acetylene flame, and the combustion gas laden with fume was passed into a suitable duct. It was found that the heat generated by the combustion of the acetylene and oxygen mixture and the exothermic reaction of the iron in forming the oxide was sufficient to raise the air temperature to 500° to 700°F. depending upon the flow rate employed (20 to 40 ft.^{3}/min.).

The experimental equipment for making these investigations consists of the feeder for producing iron oxide fume and a 6 in.-slag-wool filter holder placed in a duct system, as shown in Fig. 1. Samples of the air stream were taken above and below the filter with an all-glass filter web or paper developed for A.E.C. work which has nearly 100% efficiency for particles in the 0.3 μ range (close to the size of freshly formed iron oxide fume).

A number of layers of varying thickness and packing density of 4 μ mean diameter, spun slag wool were studied to obtain an optimum density for extended filter life. Resistance characteristics of a typical series of filters are shown in Fig. 2. Variation with thickness and density in the testing range used is linear for practical purposes.

(Continued on page 231)

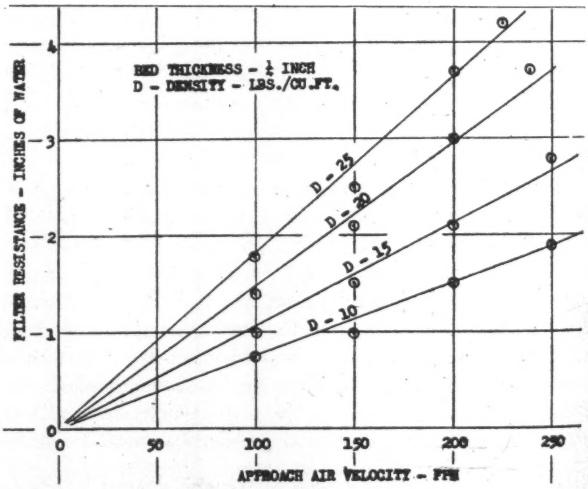


Fig. 2(b). Resistance Characteristics of Slag-Wool Filters at Constant Thickness, Varying Density.

Control of Air Pollution from Oil Refineries in Los Angeles County

CARL V. KANTER AND IVAN S. DECKERT
Air Pollution Control District, Los Angeles County, California

During the past six years the Los Angeles smog problem has been the subject of much study not only by the Air Pollution Control District, but by many other interested groups as well. Many sources have been pointed out as contributors of atmospheric pollution. Automobile exhausts, incineration of combustible refuse, metallurgical fumes, oil refineries, chemical plants, burning of fuel oil, hot mix paving plants, asphalt roofing manufacturing, railroad locomotives, ships in the harbor, and others have been blamed. Each has contributed some part to the air pollution.

Since Los Angeles County is a great industrial area and since the production and refining of petroleum is one of its largest industries, it is only natural that pollutants from refineries and related processes would receive much attention in the smog situation. This paper will discuss some air pollution problems of the oil industry and control measures.

The petroleum industry in Los Angeles County includes production of crude oil, refining of the crude, and marketing of the products. Over 300,000 bbl./day of crude oil are produced from oil fields in the County. Refining is an even larger operation, with a total throughput capacity of 687,500 bbl./day[1]. This amounts to over 8% of the total refining capacity of the United States and is the second largest concentration in the country, exceeded only by the Gulf port area of Texas.

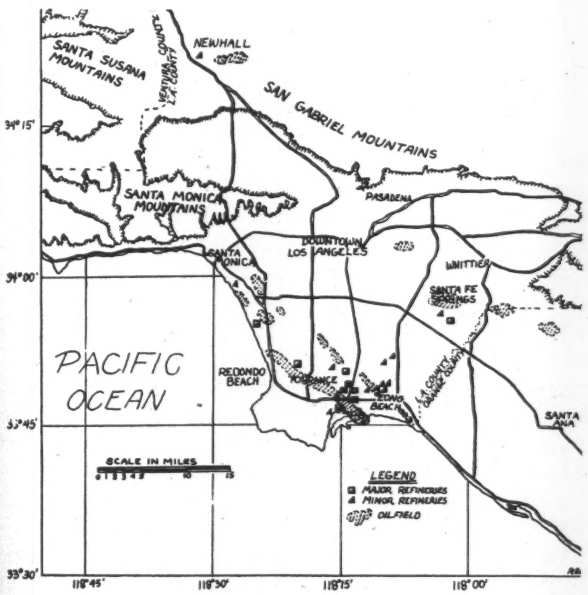


Fig. 1. Map of Los Angeles County.

Fig. 1 is a map showing part of Los Angeles County with the location of the oil fields and refineries of seven major oil companies and a number of independents. There are also three major petrochemical plants in the southern part of the County (for synthetic rubber) and a solvent plant using petroleum derived raw materials. Another large petrochemical plant is under construction.

Crude Oil Production

Air pollution from the production of crude oil will be discussed only briefly. The principal loss to the atmosphere from oil field operations consists of light hydrocarbon vapors containing mainly methane, ethane, propane and butane, with small amounts of heavier hydrocarbons. The amount of gas blown to the atmosphere today is small compared to the wastage prior to 1940 when smog was not such a problem. The gas is primarily methane and it does not appear to be a contributor to smog. Other hydrocarbons, mentioned above, are lost to the atmosphere by evaporation from the crude oil storage tanks, dehydrating equipment, and open oil-water separating ponds. Oil field operations give rise to typical odors, but these odors have long been associated with the Los Angeles scene, and do not appear to cause any undue distress to the inhabitants. Studies are being made to determine the importance of oil field hydrocarbon emissions to the smog problem.

Oil Refinery Smog Problems

The refining of petroleum into marketable commodities involves a complex integration of chemical and physical processes which give rise to many pollutants, including smoke, dusts, malodors, sulfur compounds, oil mists, and various hydrocarbon vapors. While all of these are important, the hydrocarbon vapors play a significant role in the unique aspects of the Los Angeles smog. For this reason, sources of hydrocarbon losses to the atmosphere and methods for their control will be emphasized.

Effects of Hydrocarbons

Studies made by the Los Angeles County Air Pollution Control District[2-3] show that certain classes of hydrocar-

[1] Knudsen, Edward T., "Petroleum Refineries, Cracking Plants, Natural Gasoline Plants and Cycle Plants in District Five," U. S. Dept. of Interior, Bureau of Mines, Petroleum Statistics Section, Region III, January 1, 1953.

[2] *Second Technical and Administrative Report on Air Pollution Control in Los Angeles County.* Air Pollution Control District, County of Los Angeles. 28 (1950-1951).

[3] Haagen-Smit, A. J., "Chemistry and Physiology of Los Angeles Smog," *Industrial and Engineering Chemistry, 44,* 1342 (1952).

bons in the atmosphere react under the influence of sunlight to form a variety of oxidation products, including ozonides, peroxides, aldehydes, acids, and others. Synthetic smogs formed by oxidation of gasoline or specific hydrocarbon compounds with ozone or nitric oxide show some of the typical properties of Los Angeles smog, such as eye irritation, crop damage, reduction of visibility, and characteristic odor.

Unsaturated hydrocarbons, such as olefins, appear to be much more reactive than paraffins, which are relatively inert. Branched chain paraffins are more reactive than normal paraffins.

Estimates of the quantities of hydrocarbons being emitted to the atmosphere from various sources indicate about 800-1000 tons/day from motor vehicles and about 300 tons/day from refinery operations.

Sources of Hydrocarbons from Refineries and Their Control

Storage

One of the important sources of hydrocarbon emission from refinery operations is storage of petroleum products. Extensive tank farms are maintained to store crude oil and finished products which range from liquefied petroleum gases to asphalt.

Pressure vessels are used to store light gases such as propane and butane in liquefied form, and liquids of high vapor pressure such as natural gasoline. These pressure vessels do not normally vent any vapors to atmosphere. On infrequent occasions, when the vessels are opened for inspection, the residual vapors are blown out. Upon refilling, some vapors are lost until the air is completely displaced. When low vapor pressure liquids are stored in pressure vessels some venting can occur during filling because of pressure build-up from the air in the tank. This loss can be prevented by limiting the volume stored to a calculated percentage of the tank capacity.

Relatively non-volatile materials such as kerosene, gas oil, fuel oil and other heavy products are usually stored in fixed roof tanks at atmospheric pressure. The evaporation losses from these products are not significant when their storage temperatures are not greatly above atmospheric. Problems of odors or oil mists arise, however, when higher temperatures are maintained.

It is from the storage of gasoline and other products in the same volatility range that the evaporation losses reach significant quantities. A great many studies, both experimental and theoretical, have been made of evaporation losses from storage tanks and methods evolved for estimating the losses. The subject was thoroughly reviewed at the 32nd Annual Meeting of the American Petroleum Institute[4].

In a vented fixed roof tank which is partially filled with a volatile hydrocarbon liquid, the space above the surface of the liquid will be filled with a mixture of air and hydrocarbon vapors. The percentage of vapors in the mixture will depend on a number of factors, including the vapor pressure of the liquid, surface temperature, and degree of saturation attained. The mixture of air and vapors may be displaced from the tank by filling, or by "breathing" due to diurnal temperature changes which cause the gases in the vapor space to expand and contract.

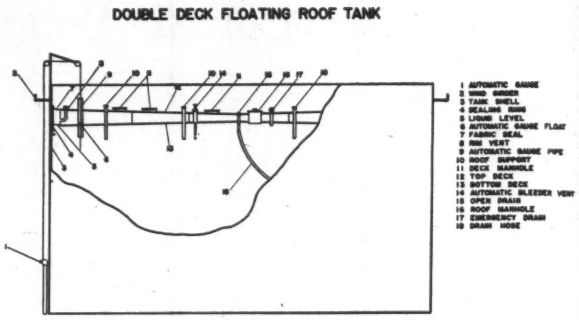


Fig. 2. Schematic diagram of a floating roof tank.

Three principal methods are used to reduce evaporation losses from storage tanks:

1. Floating roof,
2. Variable volume vapor space,
3. Vapor recovery.

Floating roofs are designed to rest on the surface of the liquid in the tank and move up or down as the liquid level changes. In this way the vapor space in the tank is eliminated and losses of vapor due to expulsion of air-vapor mixtures are prevented. The roof may be a pan, pontoon, or double-deck type. In each case the radius of the roof is about a foot less than the tank. A metal shoe, held against the tank wall by some type of spring device is connected to the floating roof, and the space between the shoe and roof is closed with a flexible fabric seal. Some losses will occur from floating roof tanks through the space between the shoe and the tank, and from the small annular vapor space formed by the fabric seal. This loss will be considerably lower than from an equivalent fixed roof tank. The percentage reduction will depend on the usage of the tank. On an average, losses will be reduced about 85% by conversion from a fixed to a floating roof.

Variable volume vapor space may be achieved in several ways. One is a so-called lifter roof which may rise or fall through a limited range as vapors in the tank expand or contract. The vapor space of a lifter roof tank may be interconnected with one or more fixed roof tanks to effect a measure of vapor conservation in all. Since the variable vapor volume is only a fraction of the total volume of the tank there will not be enough capacity to prevent filling losses. Breathing losses can be completely con-

[4] "Evaporation Loss of Petroleum from Storage Tanks." *32nd Annual Meeting*, American Petroleum Institute, November 1952.

trolled. Where several tanks are interconnected, filling losses can be reduced by balancing the pumping into and out of the tanks.

A gas holder can be used as a variable vapor volume for one or more tanks. Also, specially designed spheres with flexible diaphragms are available in capacities up to about 150,000 ft.[3] For small installations a flexible diaphragm unit can be built on the roof of the storage tank itself.

Vapor recovery systems serve to collect the vapors which are vented from storage tanks and to recover the hydrocarbons. A typical system will have pipelines of adequate size from each tank, with an automatic regulator at each tank to control the small positive pressure at which the tank will vent into the system. The vapors will be carried through a header to the suction side of one or more compressors. The non-condensed vapors may be passed through absorbers, and the remaining light gases used as fuel. Compressors and absorption equipment are usually available at a refinery. Some companies have found it desirable to repressure the tanks with natural gas during the periods when the tanks are breathing in, to avoid having too much air in the mixture going to the compressors. The tanks are fitted with vacuum-pressure breather valves for protection against abnormal conditions. These are set so that the tanks normally vent into the recovery system. When it is impractical to recover the vapors collected, they may be burned in a flare or fire-box.

The type of control used to prevent losses of hydrocarbons to the atmosphere from storage tanks depends on the size, number and location of the tanks, products stored, and the practicability of installing other facilities such as compressors, etc.

In order to determine the magnitude of the hydrocarbon losses to atmosphere from storage facilities in Los Angeles County, the Air Pollution Control District conducted an extensive survey of the oil refineries, marine terminals, bulk plants, and tank farms to determine the number of tanks, capacities, types, products stored, movement of products, and vapor control equipment installed. From these data the vapor losses to atmosphere were estimated.

It was evident from the survey that hydrocarbon

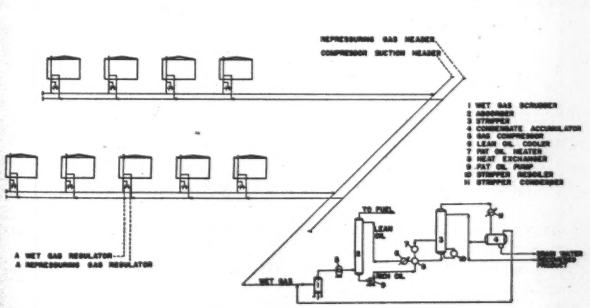


Fig. 3. Schematic diagram of a vapor recovery system for a group of fixed roof storage tanks.

Fig. 4. Part of an open oil-water separator formerly in use. Handled approximately 30,000 barrels per day of effluent water containing 1 000 barrels of oil. Evaporation of oil from surface ranged from 20 to 40 tons per day.

emissions could be reduced by about 100 tons/day if all storage tanks handling the more volatile products, such as gasoline, were equipped with vapor conservation devices. Consequently, on April 30, 1953, the Los Angeles County Air Pollution Control Board passed a rule requiring controls on all tanks storing gasoline or other petroleum distillates having a vapor pressure of 1.5 lb./in^2. or greater. A copy of the rule is given in the appendix.

The oil industry has cooperated with the Air Pollution Control District in carrying out the provisions of the rule and the construction of control devices has proceeded at a rapid rate.

Oil-Water Separators

Waste water from refinery operations is contaminated with oil which must be removed before the water can be disposed of. Oil removal is usually accomplished in open separator boxes or skimming ponds. During the retention period the oil floats to the surface where it is trapped by baffles and skimmed off. Usually a series of such treatments is required to reduce the oil content of the effluent water to acceptable levels.

These effluent water systems vary widely in the different refineries as to the quantities of oil and water handled, volatility of the oil, exposed areas of separators, methods of baffling, and skimming operations. Correspondingly, the losses of hydrocarbons to the atmosphere from these systems vary widely.

Accurate determination of the losses is difficult because of the variable nature of the operations and the large inherent errors in sampling and analytical procedures. Methods include calculations from vapor pressure and controlled weathering tests[5], comparison of inlet and outlet oil samples by very close fractionation, and measurement of hydrocarbon content of the air around the separator.

The first study made of hydrocarbon emissions from effluent water systems in the County showed a loss of about 30 tons/day from one major refinery. This indicated that overall hydrocarbon losses from this type of equip-

[5] Viles, P. S., and Jones, L. T., "Estimating Oil Losses by Atmospheric Evaporation from Refinery Separator Surfaces," *Petroleum Refiner, 31,* 117 (January 1952).

ment were of sufficient magnitude to warrant further investigation and corrective action. The oil industry cooperated with the Air Pollution Control District in the making of tests and surveys to determine the extent of the problem. The results showed that two major refineries had losses in the order of 30 tons/day each, and that the others were considerably less, ranging downward from about 10 tons/day. These losses have been materially reduced by the installation of corrective equipment.

One installation consists of a completely closed separator box with a suction line and compressor to remove the vapors to an absorption tower.

In another installation a large open separator pond has been replaced with two parallel systems having floating roof covers with automatic skimming devices.

In a third installation covers have been provided where the bulk of the evaporation occurs, at the inlet compartments and oil sumps. In this case the separator boxes are compartmentalized and about 95% of the oil is continuously skimmed off in the inlet compartment and carried into a sump from which it is periodically pumped to storage tanks.

Other plans are now under way for improving separator systems. One major refinery is planning to revamp its waste facilities completely within the next year, replacing its present system of open boxes, ponds and channels with treating equipment in which the oil surfaces will be completely enclosed. A large independent refinery is planning to segregate from its present separator those streams containing gasoline and other light oils and process them in closed tanks.

Prior to these changes the hydrocarbon emissions to the atmosphere from oil-water separator systems in the refineries amounted to more than 100 tons/day. With the changes made, and those projected for the near future, the losses will be reduced to about 20 tons/day.

Further reductions can be made by operational or equipment changes which reduce the amount of light oil getting into the effluent water system. An example of this is the reduction of drippage from pumps by use of mechanical seals instead of conventional packing.

Fig. 5. This floating roof separator replaces an open pond. The roof is divided into two independent sections; the near section contains oil-skimming equipment. Oil free water flows under wall and over weir in foreground to pond.

Flares

Occasional large releases of hydrocarbon gases occur in refinery operations due to abnormal conditions, such as failure of compressors. More frequent gas releases in small quantities result from opening of pressure control valves, leakage of safety relief valves in manifolded systems, and through depressuring of equipment for periodic maintenance. In the case of some of the smaller refineries with cracking plants, an excess of gas is produced over fuel requirements. It is very desirable to prevent the escape of these hydrocarbon vapors and gases to the atmosphere, not only as an air pollution control measure, but also to reduce fire and explosion hazards. Flares are used to dispose of hydrocarbon releases of this nature.

Flare design must provide for smokeless combustion of gases of variable composition through a wide range of flow rates. Maximum emergency flows may reach as high as 1,500,000 ft^3./hr.

All refineries in Los Angeles County have installed flares of a smokeless type. They fall into two classes—those using venturi burners to obtain proper fuel-air ratios[6-7], and those using steam injection into the combustion zone[8-9].

Venturi flares usually fire horizontally into a burner pit. One installation[6] for handling large gas volumes (14,000,000 ft^3./day) consists of four venturi burners increasing in size from 5 in. to 18 in. diam. throat. The burners cut in successively as gas pressure increases. A venturi type flare[7] for smaller gas volumes up to about 2,000,000 ft.^{3}/day makes use of standard gas burners in banks of increasing numbers of burners. These banks of burners cut in successively as gas pressure increases to certain predetermined values.

Steam injection flares are normally built with vertical stacks. The steam may be injected into the gas just below the stack outlet, or directly into the flame zone.

Automatic controls are provided on the steam lines to vary the amount of steam according to the gas flow. Smokeless combustion is effectively produced by the action of the steam in these flares. The mechanism appears to be a combination of turbulence, dilution, and chemical reaction. Turbulence improves the mixing with air, dilution inhibits the cracking of the gas, and chemical reaction produces carbon monoxide and hydrogen which

[6] Brumbaugh, A. K., Jr., "Smokeless Burning of Refinery Vent Gases," *Petroleum Processing, 2,* 168-170 (March 1947).

[7] Beychok, Milton R., "Build A Flare for Under $5,000," *Petroleum Processing.* 1162 (August 1953).

[8] Smolen, Warren H., "Smokeless Flare Stacks," *Petroleum Processing,* 978 (September 1951).

[9] *Session on Refinery Flare Design, Proceeding 17th Midyear Meeting,* American Petroleum Institute, Division of Refining, *32M III,* 145 (1952).

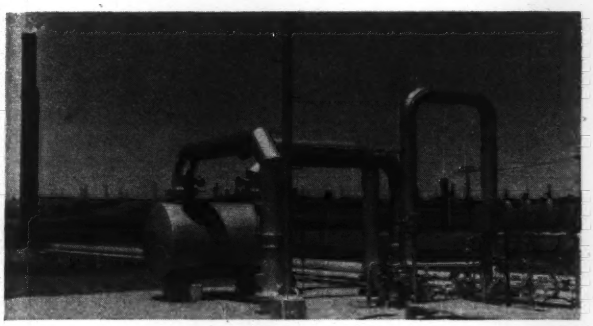


Fig. 6. Smokeless flare system for emergency gas releases. Main flare stack is located on the left and auxiliary flare in background under pipe loop. Control equipment in right foreground regulates quantity of steam to the flares for varying gas flows. Liquid knock out drum is located underground. Vessel in center is a water flashback seal. Water leg to right of vessel provides a by-pass to auxiliary flare.

burn smokelessly. Steam requirements vary with the composition of the gas and design of the flare. As little as 20 lb. of steam/1000 ft^3. of gas burned have been used with no smoke produced. Average requirements appear to be about twice this figure.

In all flare systems it is essential to provide knock-out drums to trap liquid hydrocarbons since it is almost impossible to burn the liquids without excessive smoke. Provision must also be made for flash-back prevention by means of a water seal, steam injector, flame arrester, explosion check valve, or some combination of these. For flares using pressure regulating valves it is necessary to provide a water or mercury seal as a safety relief in case of failure of the valves to open.

Vacuum Jets

All major refineries in Los Angeles are operating, or have under construction, crude vacuum distillation facilities for producing charging stocks for catalytic cracking. In all cases the required vacuum is maintained by means of steam jets. The jets are usually placed on the accumulator following the overhead condenser of the vacuum tower. There may be two or more stages with condensation of steam between the stages.

Tests made on typical vacuum jet installations venting to the atmosphere show that hydrocarbon emissions of as much as 5 tons/day are not unusual. Such results are rather surprising, since all light hydrocarbons have been removed from the materials undergoing vacuum distillation. It appears, however, that some slight cracking of the stocks takes place in the furnaces prior to the vacuum towers resulting in light ends which are not condensed under the conditions existing. These products carried out to the atmosphere are usually of a highly malodorous nature.

Nine vacuum jet systems of the type described above were found to be venting to the atmosphere. Eight of these have already been corrected with the ninth under construction.

Vacuum distillation is also used in other services such as rerunning gasolines. Losses to atmosphere will vary according to the design of the facilities and stocks processed. Each such installation must be evaluated to determine the necessity for controls.

Equipment for preventing emissions from vacuum jets is relatively simple. The effluent from the final stage is run through a condenser. The liquid collected is passed into a closed settler for separating water and hydrocarbons. The remaining noncondensable gases can be burned in a fume incinerator or existing furnace or boiler, or can be added to the plant fuel gas system.

Other Sources of Hydrocarbon Emission

Leakage from pump glands, valves and pipe fittings can result in a considerable overall loss of hydrocarbons. The solution to this problem lies in proper inspection and maintenance procedures. Pump gland losses can be greatly reduced by the replacement of conventional packing glands with mechanical seals on centrifugal pumps handling light hydrocarbons. Leakage from properly operating mechanical seals is negligible.

Air blowing of light oils in treating processes, drying, or blending can result in significant emissions of hydrocarbons to the atmosphere. It has been estimated that the doctor treating of gasoline results in a loss of up to 1%. This loss is principally evaporation, most of which occurs when the doctor solution, containing entrained hydrocarbons, is regenerated by air blowing. The loss can be greatly reduced by steam stripping the doctor solution in a closed system prior to regeneration. Air blowing processes used primarily for agitation can in many cases be replaced by mechanical mixing.

Safety relief valves are a source of hydrocarbon emission to the atmosphere not only when they occasionally pop due to operational upsets but also from continuous slight leakage when they fail to reseat properly. Accurate measurements of this loss are very difficult to make. In some refineries the relief valves are manifolded and vent to a recovery system or to a flare. In a recently installed vapor recovery system of this type, the amount of hydrocarbon gases recovered proved to be surprisingly large, amounting to about 100 tons/day. Where relief valves are not manifolded, losses can be reduced by a rigid program of inspection and maintenance of the valves. Dual relief valves should be provided in such cases, so that one can be blocked off for removal while the other remains in service.

Blind changing in pipelines accounts for about 5 tons/day of hydrocarbon vapors lost to atmosphere. This occurs when gasoline or other product trapped between valves is spilled when a line is broken to remove or place a blind. This type of loss can be reduced by use of mechanical type blinds or special valves. In some cases, modernization of the piping facilities sharply reduced the number of blind changes required and correspondingly reduced hydrocarbon losses.

Losses of hydrocarbons to the atmosphere occurring when equipment is taken out of service for inspection and repair appear to be relatively minor. Proper procedures for depressuring vessels should be adhered to in order to insure minimum emissions. Blowdown systems for collecting liquid hydrocarbons should include provisions for vapor recovery.

Refinery Pollutants Other Than Hydrocarbons

Other refinery pollutants will be discussed briefly. The brevity of the treatment should not, however, be construed as a measure of their importance.

Sulfur Compounds

Crude oils processed in Los Angeles County contain sulfur in varying amounts, averaging about 1.5%. In cracking processes, part of the sulfur is converted to hydrogen sulfide which separates with the light gas fractions. A smaller fraction of the sulfur is converted into mercaptans which must be removed from the gasoline fractions and disposed of. A large part of the sulfur remains in the heavier fractions such as fuel oil and residuum.

When gases containing H_2S, or oil fractions containing other sulfur compounds, are burned as fuel, the sulfur is released with the flue gases as SO_2 and, to a small extent, as SO_3. The latter causes a characteristic blueish-white haze.

All the large refineries in Los Angeles County have installed equipment for removing H_2S from the gases produced. The process involves scrubbing with a solution, such as diethanolamine, which absorbs the H_2S, followed by steam stripping the solution to remove the H_2S and thus regenerate the absorbing agent. The H_2S is converted into elemental sulfur or sulfuric acid.

Three sulfur plants have been built to process a major part of the H_2S. The smallest of these plants has a design capacity of 7 tons/day of sulfur, and the largest, 120 tons/day. Two sulfuric acid companies process the remainder of the H_2S.

Equipment installed since 1948 for this purpose has resulted in the removal of 300 tons/day of SO_2 previously emitted to the atmosphere.

Five small refineries have cracking units which produce H_2S in relatively minor quantities, the combustion of which releases about 20 tons/day of SO_2 to the atmosphere. A practical method for handling these small amounts has yet to be devised.

Refinery gas and natural gas account for most of the fuel used in the refineries—only a comparatively small amount of fuel oil is burned.

Mercaptans are usually disposed of by burning in a firebox or properly designed fume burner, resulting in the release of about 5 tons of SO_2 daily. Attempts to dispose of mercaptans by introducing them into the base of a furnace or boiler stack have proved unsatisfactory. One rather interesting method of disposing of mercaptans is to add them to the catalytic cracking charge stock. They are converted to H_2S in the process and subsequently recovered from the gas fractions. A small quantity of mercaptans is sold to chemical firms.

Dusts

The principal dust problem in refinery operations is found in catalytic cracking processes. Fluid Catalytic Cracking units are equipped with electrical precipitators which have successfully reduced dust emissions to the legal requirements[10].

Thermofor Catalytic Cracking units are equipped with either dynamic wet-type dust collectors or multiple, small diameter, high efficiency cyclones for removing dust from elevator vent stacks.

Smoke

Smoke is not a serious problem in the Los Angeles County oil refineries. All boilers, furnaces, and similar combustion equipment are adequately designed, with proper burners and controls. Most of this equipment operates continuously at a fairly uniform rate. All refinery flares are now of types which can burn smokelessly through wide operational ranges.

Smoke violations which do occur are usually caused by mechanical failure of some sort, such as an oil tube rupture in a pipe still or failure of automatic controls on burners.

Malodors

Of all the multitudinous air pollution problems involved in oil refinery operations, malodors are probably the greatest cause of specific complaints. Some of the malodorous compounds, such as mercaptans, can cause noticeable odors over great areas when extremely small quantities are liberated. Numerous refinery processes are potential sources of malodors. These include acid treating, doctor treating and other mercaptan removal processes, caustic regeneration, cresylic and naphthenic acid manufacturing, air blowing of asphalt, and many others. In practically every case the successful solution of the odor problem involves the burning of the malodorous vapors and gases in a combustion chamber or fire box with a temperature of at least 1200°F.

Summary

Air pollution in the Los Angeles area is a complex problem. That aspect of the problem relating to the petroleum industry and particularly to the oil refineries has been discussed. It is evident that a great deal of progress has been made in controlling sources of hydrocarbons and other pollutants from refinery operations. While progress has been great, there are still areas where further improvements are needed. These can be realized by a sound engineering approach to each specific problem, including process studies and evaluation of losses, followed by design and installation of control equipment.

(Continued on page 212)

[10] Rule 54, *Rules and Regulations*, Air Pollution Control District, County of Los Angeles.

Dust and Fume Problems in the Cement Industry

Richard O'Mara, Carl Flodin and Robert Plass
Western Precipitation Corporation
Los Angeles, California

Daily each of us touches upon or comes in contact with cement. Transportation, with its great highways, airports and bridges, depends greatly on concrete. Reclamation and hydroelectric projects use it in vast quantities. Our buildings, warehouses and industrial plants use it for strength, durability and protection against fire. The towering steel structures of our skyscrapers rest on foundations of concrete. And below the surface of the ground, cement is used in mines, and in oil wells it is placed to reinforce steel pipe and protect producing zones to depths of nearly 4 miles. And what would our homes and farms be without cement?

Cement has an ancient history. The foundations of most of the buildings in the Forum in Rome were a form of concrete. The Colosseum and the huge Basilica of Constantine built about 27 B. C. are examples of Roman architecture in which a type of cement mortar was used.

As with other developments of the great Roman era, the production and use of cement moved westward. It was not until 1824, however, that an English bricklayer named Joseph Aspdin patented a process wherein a predetermined and carefully proportioned chemical combination of lime, iron oxide and alumina was pulverized, burned into a clinker, and then ground into finished cement. Thus was Portland cement born, and so named because it resembled in color the stone quarried on the Isle of Portland off the British Coast.

The first Portland cement was shipped to the United States in 1868 and by 1895 had reached a peak import volume of 3,000,000 bbl. Americans began producing increasing amounts of Portland cement for themselves and by the turn of the century were manufacturing 500,000 bbl./yr. Today our production is approximately 250,000,000 bbl./yr.

Although the fundamental principles utilized in the manufacture of cement are substantially the same as those described by Joseph Aspdin, modern cement making techniques are naturally far advanced with better quality as well as greater quantity resulting from improved design and efficiency in larger units and larger plants. The horizontal rotary kiln was patented in 1885 but it was not until 1902 that the first long rotary kiln was introduced by Thomas Edison in his Edison Portland Cement Works.

A comprehensive view of the present process for making cement is given in the isometric flow chart prepared by the Portland Cement Association[1] as shown in Fig. 1.

In modern cement manufacture there are dust and fume problems which vary with the location of the plant and with the type of installation. The selection of suitable equipment for removal of fume and dust will naturally be influenced primarily by technical and geographic requirements, and by economics.

The raw materials, consisting essentially of limestone, shale, oyster shells, clay, marl, iron ore and silica sand are quarried in the conventional manner and are crushed and stored. Dust is little or no problem here.

The raw materials are ground, mixed and blended by either the wet or dry process. There are now some 90 plants using the wet process and about 63 using the dry process. With the present high cost of fuel, there is a trend to the dry process plant. Here again, the dust problems are simple and straightforward.

The wet or dry mix is next fed to a rotary kiln where it is burned and clinkered. The waste gases from the kiln contain varying amounts of dust and fume and constitute the major gas-cleaning problem in the cement-making process. This will be discussed in detail later.

Clinker from the kiln is cooled on its way to storage. The most common method of clinker cooling is air quenching with atmospheric air. Part of the air thus heated is used for secondary combustion in the kiln while the remainder is passed to the atmosphere. The Holo-Flite Processor has been used for clinker cooling by indirect heat exchange.

The use of centrifugal or louver type collectors to clean this waste gas is very profitable since 1 to 2% of the kiln production can be recovered and most clinker coolers are equipped with collectors.

The cooled clinker is finally pulverized and blended with gypsum in the finish mill department and stored or

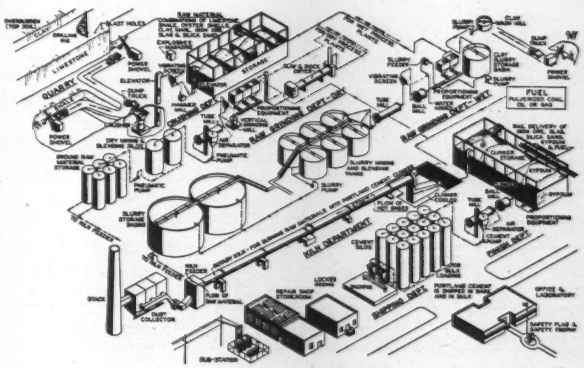


Fig. 1. The Manufacture of Portland Cement.

	DUST CHAMBERS	LARGE DIA. CYCLONES	MULTICLONES	SKIMMER TYPE COLLECTOR	CLOTH FILTERS	CORROSIVE COLLECTING ELECTRODES	METALLIC COLLECTING ELECTRODES	COMBINATION CORROSIVE & METALLIC ELECTRODES	COTTRELL SCRUBBERS
QUARRYING OPERATIONS			•		•				
PRIMARY CRUSHING			•		•				
RAW MATERIAL DRYERS			•				•		
DRY PROCESS									
RAW GRINDING			•	•	•		•		•
KILNS WITH WASTE HEAT BOILERS	•	•	•			•	•	•	•
KILNS WITHOUT WASTE HEAT BOILERS	•	•	•				•		•
KILNS WITH PRE HEAT SYSTEM		•	•			•	•	•	•
WET PROCESS									
KILNS WITH & WITHOUT WASTE HEAT BOILERS	•	•	•				•		•
COAL HANDLING & GRINDING		•	•		•		•		•
CLINKER COOLER		•	•	•					
FINISH MILLS					•		•		
BAGGING & SHIPPING			•		•				

Fig. 2. Air Cleaning Equipment and Application for Cement Plants.

shipped to users. The major portion is shipped in bulk by truck, rail or ship; smaller quantities are shipped in bags. Dust problems in the finish mill and the shipping departments are not complicated and are usually handled with cloth filters of various types.

Fig. 2 shows a check chart list of the sources of dust in the cement-making process and the type of equipment generally used for cleaning the gases.

Fig. 3 shows particle size distribution for dust and fume in dryer and kiln gases. It will be noted that for high recovery efficiencies, Cottrell Electrical Precipitators or filters are indicated.

Cement-Making Process

The dusts created in the cement industry, unlike many other furnacing operations, are mostly those that are ordinarily found in the atmosphere and they have little or no harmful effects on plant or animal life. Under certain conditions, however, they can become a nuisance; and the industry early realized the importance of cleanliness, both inside and outside the plant.

Wherever possible, plants are located as near to the quarries and sources of supply of raw material as conditions permit. They are usually built in open country and, because of the low value of the stack dust, many of the early installations did not use any dust collectors. However, the plants have attracted residents and the trend toward suburban living has caused large communities to grow up around them. With this population change, the older plants have been required to install effective dust collecting systems and the new plants to incorporate them in the original installations.

The kiln is a major source of dust and fume and one of the principal sources about which the plant's neighbors will complain.

In the burning and clinkering process in the rotary kiln (wet or dry), dust is carried out with the waste gases. Where the raw material contains alkaline earths or salt, the alkalies are volatilized and carried along as a fume, usually under one micron in size. Waste gases discharged from the rotary kiln range from 400 to 1600 degrees F. and carry suspended solids in the order of 2 to 10 gr./ft^3.

The problem was first attacked at the Riverside Cement Company plant in Southern California where dust from the kiln stacks had become the cause of serious damage suits. About this time, Dr. Frederick G. Cottrell commercially adapted the electrostatic process for the treatment of certain gases and his former student, Mr. Walter A. Schmidt, who was, and still is, President of Western Precipitation Corporation, undertook to apply the Cottrell process to the Riverside stacks. After a year of study and experimentation, the problem of treating the hot kiln gases was successfully solved and a large commercial Cottrell Electrical Precipitator installation was built to treat approximately 1,000,000 ft.^{3}/min. of gas. This installation was put into operation and is still in service as originally constructed. During the intervening 42 years it has collected well over 1,000,000 tons of dust. The original mechanical rectifiers are still in daily operation and the Cottrell precipitation units themselves have been repaired from time to time as required, but the original designs are still in use. A recent test on the installation, as shown in Fig. 4, indicated that it is operating at an efficiency in excess of 96%.

It was once thought that the development work of adapting the Cottrell process to a rotary cement kiln was com-

PARTICLE SIZE ANALYSIS OF DUST SAMPLES FROM STACK GASES

TABLE I

PLANT	+325 MESH	-325 MESH	MICRONS -50	-40	-30	-20	-10	SURFACE AREA SQ.CM/GRAM
A	2.3	97.7	92.5	88.3	84.8	66.0	40.5	2620
B	4.0	96.0	92.2	90.0	83.3	65.8	35.2	2384
C	10.9	89.1	85.8	75.7	65.7	46.8	17.7	1323
D	6.5	93.5	90.0	83.6	73.4	53.7	19.0	1432
E	9.0	91.0	83.6	80.9	69.8	53.9	23.1	1525
F	3.0	97.0	93.3	89.1	81.5	70.1	41.3	2650
G	7.9	92.1	88.5	81.6	72.2	53.8	22.3	1600
H	12.8	87.2	84.2	78.6	68.3	52.7	25.0	1617

PARTICLE SIZE ANALYSIS OF DUST SAMPLES FROM ROCK & SHALE DRYERS

TABLE II

SAMPLE	+325 MESH	-325 MESH	MICRONS -50	-40	-30	-20	-10	SURFACE AREA SQ.CM / GRAM
I	4.4	95.6	87.8	81.5	72.5	55.5	23.8	1791
J	11.2	88.8	81.1	75.3	66.0	51.4	24.0	1542
K	6.5	93.5	90.9	83.4	72.8	53.6	24.0	1628

Fig. 3. Particle Size Distribution of Dust and Fume in Dryer and Kiln Gases.

Fig. 4. Riverside Cement Company Plant.

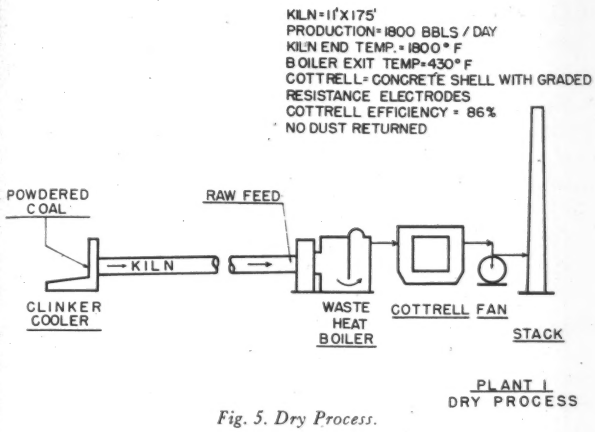


Fig. 5. Dry Process.

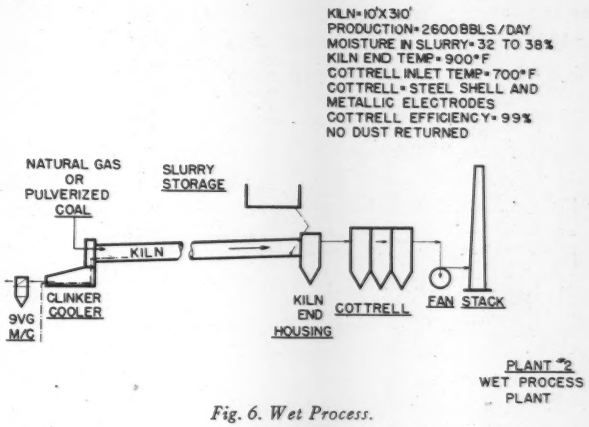


Fig. 6. Wet Process.

pleted but it was soon found that additional work was required since there are no two plants that are exactly alike. They all use different raw materials and sometimes, even in one plant, there will be two different types of kiln operation. A few of the factors affecting the selection of suitable dust collection equipment for treating cement kiln gases are:

1. Type and source of raw mix materials.

2. Types of kiln feed: dry process; wet process; filter cake feed.

3. Type of burning with rotary kiln design: Short kiln 60 to 200 ft.; Long kiln up to 500 ft.; Multiple stage burning arrangement, such as the Lepol kiln, where the drying, calcining and clinking are carried out separately.

4. Heat recovery: waste heat boilers; kiln feed preheat systems; chains in the feed end of the kilns.

5. Type of fuel: coal; oil; gas.

It is beyond the scope of this paper to discuss in detail the relative effects of the various factors in the selection of recovery equipment. We have chosen 8 plants, each of which typifies some particular variation of the cement-making process. These will be discussed individually to show the application of dust collection equipment now in use.

Figure No. 5—Plant No. 1

Plant No. 1 indicates diagrammatically an installation made some 25 years ago on a dry process cement plant in which the gases are passed through waste heat boilers and treated in a Cottrell precipitator having a concrete shell with graded resistance electrodes. These collecting electrodes are precast concrete with embedded steel to provide for a uniform high voltage gradient at the plate surface. This has been proved by experience to have certain advantages in dry process plants where the gases are cooled by means of a waste heat boiler and the dust ordinarily has a relatively high resistivity.[2-3] Details of the operation of the Cottrell process, as well as the relative effects of resistivity of dust on the operation, have been covered rather fully over a number of years and further information is available in papers noted in the Bibliography.

The dust carried by the gases contains both alkalies and sulfur, thereby requiring that all of the Cottrell dust be discarded. This plant is located in a rural area and the company has acquired large land holdings in the vicinity so that high efficiency was not required at the time the original installation was made.

Figure No. 6—Plant No. 2

This is an example of a wet process plant in which slurry containing 32 to 38% moisture is introduced directly into the kiln and natural gas or pulverized coal is used as fuel. The composition of the raw mix is such that although the total alkali content of the dust is low, no dust is ordinarily returned. However, at times 40 to 50% of the dust has been returned to the kiln.

The Cottrell has a steel shell with three sections of electrodes—the first two sections being of the rod curtain type and the third section being of the pocket type. The plant is located in the heart of a small community and the efficiency of the Cottrell is very high.

Figure No. 7—Plant No. 3

This shows diagrammatically the operation of a dry process plant using blast furnace slag. The slag, together with

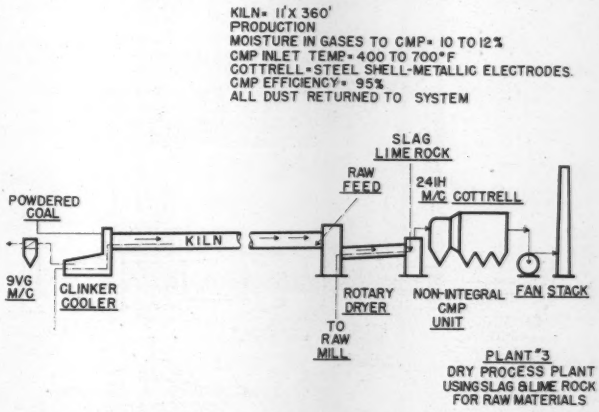


Fig. 7. Dry Process Using Slag and Lime Rock for Raw Materials.

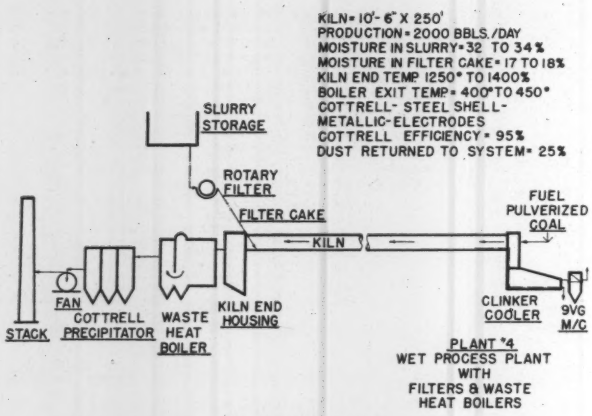


Fig. 8. Wet Process with Filters and Waste Heat Boilers.

crushed lime rock, is dried in a rotary dryer using heat from the kiln gases. From the rotary dryer this mix goes to the raw mill for preparation as kiln feed.

The recovery equipment consists of a combination of Multiclone collectors followed by a Cottrell precipitator, and operates in a temperature range of 400° to 700° F. depending upon the operation of the dryer and the amount of moisture in the raw materials fed to the dryer. The kiln is of the dry process type. This is a new plant and it is anticipated that all of the dust will be returned to the system.

Figure No. 8—Plant No. 4

Plant No. 4 is a wet process plant much the same as Plant No. 2, with the exception that rotary filters are installed between the slurry storage tanks and the kilns. This reduces the moisture in the slurry from 32-34% to 17-18%, and thereby reduces the fuel requirements for burning. Waste heat boilers are also used for further heat recovery and the gases are treated in a Cottrell precipitator having a steel shell. The collecting electrode system consists of three sections in series, the first two sections being the rod curtain type and the third section being the pocket type. Approximately 25% of the dust is returned to the system and the remainder is discarded.

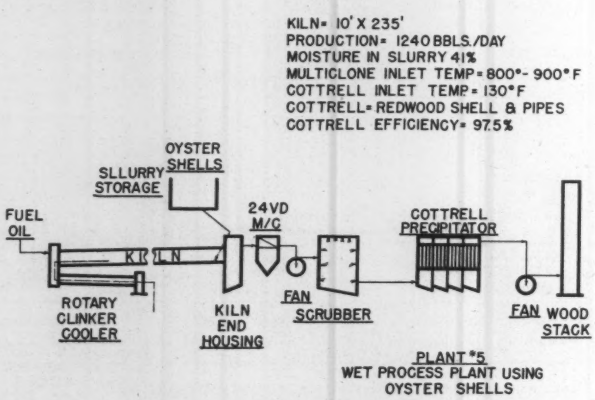


Fig. 9. Wet Process Using Oyster Shells.

Figure No. 9—Plant No. 5

Plant No. 5 shows a novel operation, in which oyster shells are dredged from beds in a bay, and the mixture of mud, salt water and oyster shells used as raw materials. They are washed sufficiently in the dredging operation so that the proper proportions of cement-making constituents are obtained for the preparation of raw mix for the kilns.

The waste gases are first passed through Multiclone collectors and this dust is returned to the kilns. The salt is volatilized in the kilns and passed through the Multiclones in the vapor phase at 800° to 900° F. Treatment in a scrubber condenses the salt fume; and the fume, together with a substantial part of the residual dust, is removed in a pipe-type Cottrell precipitator consisting of 10 in. diam. Redwood pipes, 12 ft. long, in a Redwood shell. The high voltage system consists of lead covered steel bus bars supporting Hastelloy C wires with weights.

These gases are highly corrosive and are handled through a rubber lined steel fan to a wood stack. Waste water from the scrubber and precipitator is returned to the Bay. Since this plant is located near a select residential area, it is important that the waste gases be consistently cleaned to a very high efficiency.

Figure No. 10—Plant No. 6

Plant No. 6 is a wet process operation in which the raw material is first put through a flotation beneficiation process and fed to relatively long kilns. Approximately 80 ft. of the feed end of the kilns is equipped with chains for heat recovery with a resultant exit gas temperature of approximately 500° F. This permits the use of a Cottrell precipitator having a concrete shell. The collecting electrodes are of the rod curtain type throughout. Because of the very large size of the installations, two stacks are provided to give good gas distribution through the Cottrell precipitator. Approximately 800 to 1,000 tons of dust are recovered per day. Since this valuable raw material is low in alkali, the plant developed a means for adding some additional clay to give the proper mix, which is then nodulized and introduced into a single kiln.

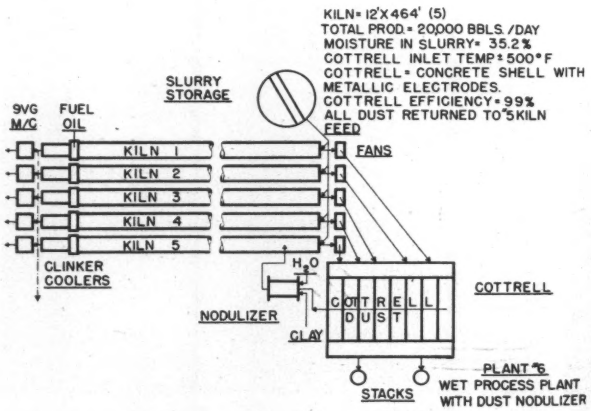


Fig. 10. Wet Process With Dust Nodulizer.

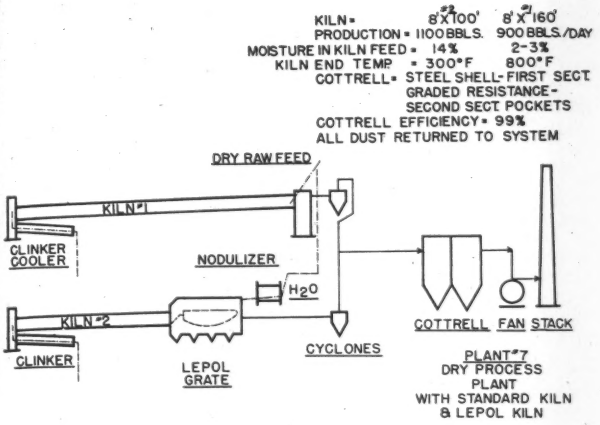


Fig. 11. Dry Process with Standard Kiln and Lepol Kiln.

The plant is located in an area containing highly valuable real estate with expensive homes, orchards and truck gardens; and because of the enormous size of the operation, over-all recovery efficiencies well over 99% are required.

Figure No. 11—Plant No. 7

Plant No. 7 might be called a hybrid installation, since it consists of a conventional dry process kiln operating in parallel with a Lepol kiln. In the Lepol kiln the raw material is first nodulized, then dried and partially calcined on a travelling grate, somewhat as is done on metallurgical sintering machines. The grate discharges into a rotary kiln and the waste gases from the kiln pass through the grate. They have the advantage of reducing the fuel required per barrel of cement produced. There are many of these plants in Europe, but very few installations of this type are in operation in the Western Hemisphere.

The gases from each kiln are passed through cyclones and then through a Cottrell precipitator. The process is complicated due to the fact that there may be times when either the dry process or the Lepol kiln may be out of service; consequently, the precipitator must be able to handle dusts having very wide ranges of moisture and resistivities.

The Cottrell precipitator consists of a steel shell, the first section being of the graded resistance type electrodes and the second section being of the pocket type. The precipitator efficiency is in the order of 99% and the over-all efficiency (including the cyclones) is much higher, with a resultant dust loss to the atmosphere of approximately 0.02 gr./ft^3.

Figure No. 12—Plant No. 8

Plant No. 8 shows a novel method of heat recovery with dry process operation, in which the raw material is introduced countercurrently to flow of the waste gases. With this system, all of the raw material is dispersed in the outlet gases and multiple stage cleaning is required. A plant of this type has heat economies comparable to the Lepol kiln.

Summary

These typical examples of a few of the 164 cement plants currently operating in the United States and Canada show the wide variations in the details of the cement-making process, as well as the problems involved in the

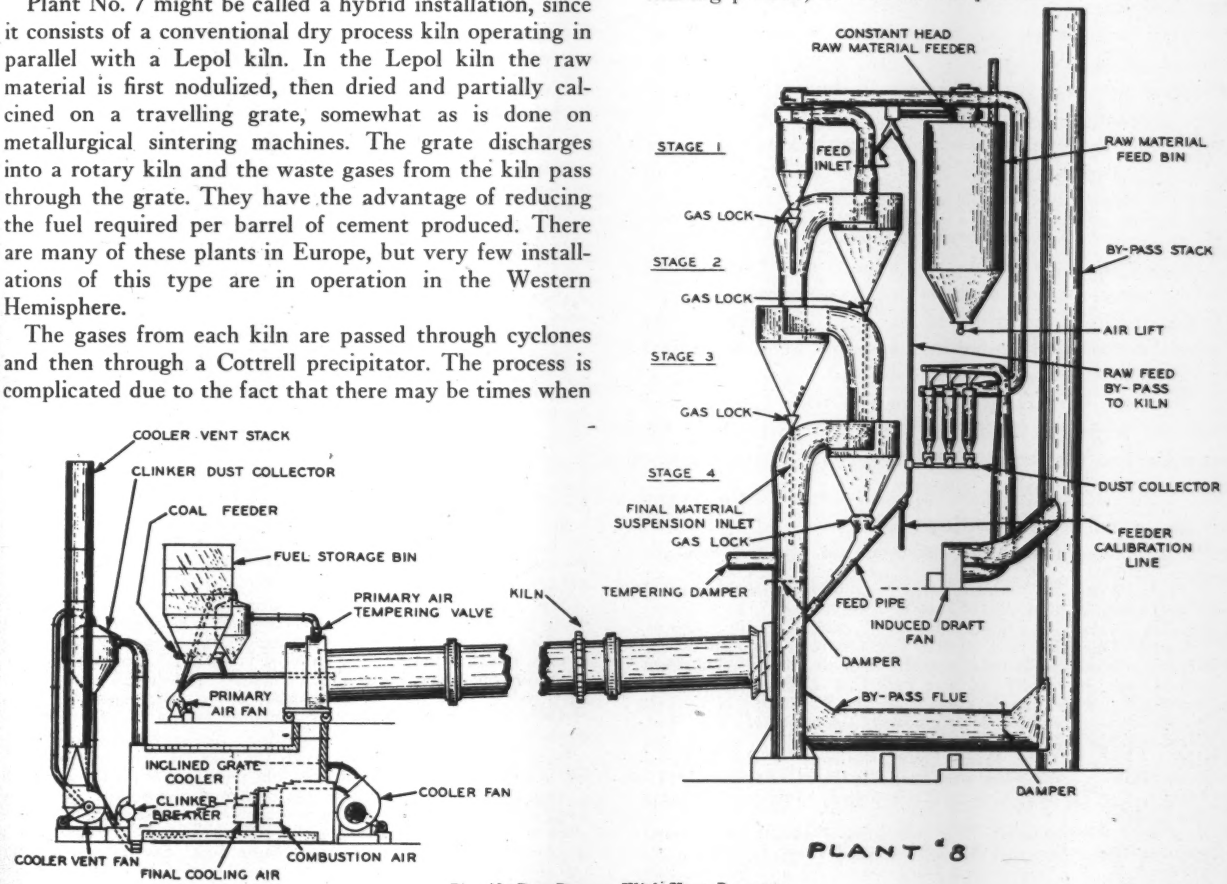


Fig. 12. Dry Process With Heat Recovery.

selection of suitable dust recovery equipment to provide the required efficiencies.

The delivered and installed cost of mechanical collectors is $0.25 to $0.50/cfm., and electrostatic precipitator cost will range from $0.80 to $2.00/cfm., depending upon the efficiencies required.

The draft loss required for the operation of mechanical collectors is 2 to 2.5 in. water column, and for electrostatic precipitators, 0.5 in. Power requirements for Cottrell operation are 8 to 10 kw./1,000,000 ft.^{3} of gas cleaned.

Mechanical collectors require no regular attention by the operators, and precipitators are equipped with automatic devices so that they can be operated with existing plant personnel. Only periodic inspection and check is required and no specialized operators are necessary.

Either mechanical or electrical precipitation equipment requires very little maintenance of upkeep, and whatever is necessary can usually be taken care of during one of the periodic kiln shutdown periods.

The cement-making process is essentially a clean one from the standpoint of damage to plant and animal life. The dust loss has a relatively low value and in many cases the recovery equipment is very expensive. However, all of the new modern plants that have been installed in the past few years have been equipped throughout with dust recovery apparatus. In some cases, managements of cement companies have not only installed equipment which is adequate for conditions as they exist now, but they have laid out the stack and associated equipment in such a way that without serious disturbance to the operations they can install additional collection equipment to raise the efficiency if required.

Acknowledgments

The authors wish to take this opportunity to thank the Fuller Company, of Catasauqua, Pennsylvania, for permission to use the drawing of Fig. 12, showing the Fuller Preheater—Humboldt Suspension type. Appreciation is also expressed to the Portland Cement Association for use of material contained in their Cement and Concrete Reference Book for 1954, and particularly for permission to use the isometric flow chart illustrating the manufacture of Portland cement.

Bibliography

1. Portland Cement Association, "Cement and Concrete Reference Book" (1954).
2. Schmidt, Walter A., "Electrostatic Precipitation and Mechanical Dust Collection," *Ind. Eng. Chem. 41*, 2428 (1949).
3. Schmidt, Walter A., Sproull, Wayne T., and Nakada, Yoshinao, "How the Operation of a Cottrell Precipitator is Affected by the Resistivity of the Collected Material." Presented at the 170th General Meeting of A.I.M.E. in New York City (February 15, 1950).
4. Sproull, Wayne T., and Nakada, Yoshinao, "Operation of Cottrell Precipitators—Effects of Moisture and Temperature," *Ind. Eng. Chem., 43*, 1350 (1951).
5. Hadley, Earl J., "The Magic Powder—History of the Universal Atlas Cement Company and the Cement Industry," Putnam (1954).
6. Witt, J. C., "Portland Cement Technology," Chemical Publishing Co., (1947).
7. Hass, P. S., "Permanente's Dust Nodulizing Process Effects Economies and Higher Output," *Pit and Quarry*, January (1952).
8. Robinson, A. W., "Eliminating Stack Dust," *Pit and Quarry*, July (1938).

DISCUSSION OF PAPER BY R. F. O'MARA, et al., ENTITLED "DUST AND FUME PROBLEMS IN THE CEMENT INDUSTRY"

Messrs. O'Mara, Flodin and Plass have passed over the dust problems connected with quarrying, crushing, drying, and raw material and clinker grinding with statements that "dust is little or no problem here." "the dust problems are simple and straightforward," and "dust problems . . . are not complicated and are usually handled with cloth filters of various types." They probably mean that relative to the problem of separating the dust and fumes from kiln exit gases, these problems are less complicated. If that is their intention, I will agree in general. But please do not conclude that these dust problems can be satisfactorily and economically solved without careful and skilled engineering.

Consider the crusher, which is frequently close-circuited with a vibrating screen. When broken rock from the quarry is dumped from railroad cars or auto trucks into the crusher, there is a rapid displacement of air from the confined spaces of the crusher or its feeder. The first problem is to corral the dust-laden air. Entrance to the feeder or crusher must be open to receive freely the discharge from cars or trucks, yet some means must be provided to control the rush of dust-laden air. Once under control, it is relatively simple to remove the dust from the air with cloth filters.

Next is the vibrating screen. The nature of this unit necessitates relatively wide clearances between the moving and stationary parts. The problem is to seal these clearance openings against escape of dust generated by the screen operation. Rubber, cloth, and other fibrous materials generally will not withstand the fatiguing movement of the rapidly vibrating screen. If the escape of the dust can be prevented, it is relatively simple to filter it from controlled ventilating air with cloth filters.

Approximately 40% of the cement plants in this country operate on the dry process; that is, all moisture is removed from the raw materials —generally limestone, chalk or marl and clay, shale, or blast furnace slag. If the moisture contents of these materials, as proportioned for the chemical requirements of the mix, are relatively uniform and do not exceed say 4%, the moisture can be removed in the grinding circuit by passing large volumes of heated air through the system. The collection of dust from this air is not always simple. The moisture may cause fungus growth on the filter cloth. To insure against condensation, the air temperature must be moderately high. Occasionally, the furnace operation is mishandled or gets out of control. Also, some raw materials, blast furnace slag for example, contain oddly shaped glassy particles with sharp cutting edges. Dust-laden moist gases from these drying-grinding operations may rot, wear, or cut holes in the filter cloth. An inconceivably large amount of dust can escape through relatively small holes. Under such conditions, the collector must be taken off for repairs. The cost of the replacement filter is insignificant when compared with the loss of operating time of the large machines with which the collector is connected. Frequently, this lost production shuts down other machines in series with the unit in question and thus may affect the operation of major portions of the entire plant.

Most of the above comments relative to dust-collecting problems of raw material crushing and grinding are applicable to clinker-grinding operations. There are numerous types of crushing and grinding machines employed in the cement industry for raw material and clinker grinding. All of them are potential sources of dust. Hence, as with the crusher, the first problem is to minimize the amount of vent air or gas; the next, to conduct it to the collector; and finally, to filter the dust from the air or gas. It is frequently the last step, namely filtering, which is the simplest. It should be noted that there is need for well designed, installed and operated duct systems[1]. The ducts must be proportioned to insure dust-carrying velocities; they must be streamlined to reduce pressure losses and abrasive wear; and, frequently, they must be insulated to prevent condensation.

Now, a little more regarding cloth filters. In our opinion, they should never be used to remove heavy loadings of dust. Rapid build up of the dust cake on the filter cloth causes excessive pressure loss which, in turn, throttles the air flow. Reduced volume of air reduces the velocities in the ducts below dust-carrying requirements and plugged ducts result. The cure is mechanical dust traps, generally simple cyclones, to reduce substantially the dust loading before the gases reach the filters.

Perhaps I am spending too much time on the "simple problems." Let us get on to dust removal from kiln exit gases. With the exception of long kilns equipped with heat exchange elements, kiln exit gases range from 1000° to 1500°F. The first problem is to reduce this temperature to ranges where ordinary metals and material may be used—Let's say to 650°F. or lower. How can this be done? Several methods are available for use either separately or in combination. We will briefly discuss the most practical. First, if economics justify, waste heat boilers

can be used. However, with current high installation and operating costs, small steam power plants seldom can compete with public utility power. Next, atmospheric air may be added to the hot gases, but such additions may double or triple the volume of gas, or water may be atomized into the kiln exit gases. The flash evaporation of water effectively reduces the temperature. However, this can be a diffcult operation. Substantial portions of the dust in the kiln gases are hydraulic and, if wet by water, will set up into concrete. Consequently, any moisture not flash evaporated may present serious problems.

With regard to tempering the gas with atmospheric air, perhaps few who have not had the experience would dream that cold, atmospheric air and hot gases (1000°+F.) mix like oil and water. Temperature stratified air can raise havoc with an electrical precipitator. And we repeat that when atmospheric air is added to reduce the temperature, the gas volume is increased greatly. Most dust collectors are volume machines. So, an increase of 2 to 3 fold in volume means 2 to 3 times the size of collector required. Consider the space requirements and the increased investment.

Mecnanical dust collectors may be used on kiln gases when their range of efficiencies will solve the local problem. However, few of these will consistently collect more than 80 to 85% because of the high percentages of minus ten micron material in kiln dust.

Electrical precipitators will, in general, perform relatively satisfactorily at proper temperatures and with properly conditioned gases. On the other hand, identical installations can be expected to perform differently in different plants even if gas volumes and dust loadings are quite similar. For some unknown reason (unknown at least to me), some gases must be tempered with moisture, to say 10%, before adequate voltages can be carried between the precipitator electrodes. In other cases, good operation is experienced with relatively dry gases. In some cases, the best collection can be attained with gas temperatures between 600° and 700°F.

An electrical precipitator performs better on the very fine particles. Greater percentages of plus 200 mesh particles have been found in the gases leaving the precipitator than were in the entering gases. While we think of a precipitator as a volume machine and engineer it for a rate or velocity of gas flow between the discharge and collecting electrodes, certainly the concentration of dust in the gases has marked effect upon the over-all removal. Consequently, to remove all the coarser particles and as much of the total dust as possible, we favor installation of a highly efficient mechanical collector, preferably of multi- or nested-cyclone type ahead of the precipitator. These cyclones should remove consistently 80 to 85% of the dust, leaving only the very fine particles for the precipitator. Under these conditions, the latter can be expected to perform much more satisfactorily.

Despite available literature and conference discussions, we in the cement industry consider dust collection one of our most difficult problems both to engineer and to operate. To make the problem worse, most of the dust collected, other than fine clinker and finished cement, will not cover the operating costs of the collecting system, let alone justify (from the value of the material recovered) the capital investment required. Generally speaking, we engineer at or towards a dust collecting problem. Results are not accurately forecastable. Let's hope that research, engineering, development and experience soon make this art an established and reliable science.

In most wet process operations, a high proportion of the dust collected from kiln gases is wasted. To return it to the kiln builds up circulating loads within the system to a degree that the stack clearance is seriously affected. Furthermore, the specification for certain cements forbid return of the dust into the kiln. Apparently, many here are familiar with the fly ash disposal problems of power plants. They should appreciate the problem of disposing of unusable, collected dust from wet process kiln operations.

Despite the engineering and operating difficulties, and the high cost of dust collecting installations, we in the cement industry are seriously and tenaciously endeavoring to solve these problems. In serving our customers, we serve the public generally and we highly value the good will and opinion of our neighbors.

1 Dohrmann, H. C., Gallaer, C. A., and Schindeler, J. W., "Factors in the Design and Operation of Industrial Dust Collectors as Related to Air Pollution," AIR REPAIR, 4, 31 (1954).

HENRY P. REID
Universal Atlas Cement Company
New York, N. Y.

The authors have presented a very interesting paper dealing with dust and fume collection in the cement industry. The fact that cement dusts are nontoxic to either humans or vegetation makes such collection a question of economics. The dusts occurring in our grinding and crushing systems are relatively easy to collect and their collection is economically feasible. 85 to 90% collection of the dust in the waste kiln gases is relatively easy to obtain and is also economically feasible. The balance of the dust and fumes in these gases are most costly to collect and of very little economic value to us.

The authors illustrate in this paper how dust collection procedures differ in eight plants, each of which typifies a particular variation of the cement making process. Our 3 plants differ in collection processes, and we are sure that even if the physical equipment were of the same nature and plan, variations in raw materials would necessitate different collection details.

Plant No. 5 illustrates the collection of material in the vapor phase. This is of particular interest because it is the belief of some that the alkalies are in a vapor phase at a very low temperature. The International Critical Tables on vapor pressure as prepared by the National Research Council deal only with those vapors which have reached an equilibrium. There is much evidence in industry to support the theory that vapors may be present in industrial systems in a supersaturated condition. An impingement of these vapors on some object will generally cause condensation of the vapor.

We are most interested in the Humbolt suspension preheater plant as shown on Fig. 12, and as to how such an installation will affect the design of dust collection systems.

We are particularly gratified that the authors have presented this paper to this group because it shows some of the problems our industry faces in producing clean gases. Unfortunately, gas cleaning is not an exact science. We know of several installations where both manufacturer and buyer confidently expected good results based on past experience, but were disappointed with the effectiveness of the collection unit after operations were inaugurated.

We are confident that continued research and cooperation between manufacturers of collection equipment, users, technical societies and public agencies will bring about greater effectiveness in the future.

F. T. SHEETS, JR.
Southwestern Portland Cement Company
Los Angeles, California

(Continued from page 187)

Air Control of Kaiser Steel Corporation

public relations program go hand in hand with a sound technical program. As indicated previously, the Kaiser Steel Corporation has had an air control program for years. However, until 1952, some of our neighbors were condemning us for the "smog" in the area and also for not doing anything about it.

Late in 1952, Mr. Earl S. Reynolds, our Director of Public Relations, initiated an educational public relations program regarding air pollution. Periodic reports were made to newspapers in 17 communities telling of our progress. Invitations to visit the plant were made to city, county, and state officials; civic groups; Farm Bureau organizations; executives of other industries; college and university professors; and other interested individuals. Local citizens were invited to take part in the tours. The editor of the plant newspaper was requested to run a series of articles on air pollution, explaining the facts to our 7,000 employees and their families. The reporters conducted a survey of our employees to see if any specific questions were not explained in the articles. Every question asked by an employee was answered in the next issue of the paper.

It has been most amazing (and pleasing) to see the change in the attitude of the citizens. The grumbling has been replaced by an attitude of tolerance. Informed citizens now realize that this is a complex problem and, as a result, can appreciate the need for research. They further realize that research often takes a long period of time.

Twenty Years of Air Pollution Control in Chattanooga

EMERSON P. POSTE
Chattanooga, Tennessee

Uncontrolled combustion of solid fuels formerly caused serious air pollution in Chattanooga. However, with improvements in burning equipment and in fly ash control, coal and wood have lost much of their stigma. And progress has been made in the control of air pollution from other sources, chiefly from metallurgical industries.

Topography and Climatology

It may be seen (Fig. 1) that Chattanooga is located in a valley, from 4 to 5 miles wide, with Missionary Ridge on the east and a series of hills and ridges to the west. The latter are approximately in line with Lookout Mountain, on either side of which is a valley extending to the south. East of Missionary Ridge there are no topographical obstructions for many miles, but to the west of the hills and ridges north of Lookout Mountain, at a distance of approximately 4 miles, are Signal Mountain and other members of the eastern portion of the Cumberland Plateau. Lookout Mountain and the Cumberland Plateau are approximately 1300 ft. above the city, while Missionary Ridge and the ridges and hills west of the city rise 100 to 230 ft. above the valley. Thus the city is confined east and west by relatively low elevations, and further to the west and partially in the southwest by mountains of considerable altitude. The Tennessee River winds through the valley, frequently contributing a high humidity. The downtown portion of the city is nearly surrounded by industrial areas and railroad yards near which are commercial and residential areas. Large residential areas are located on and east of Missionary Ridge, and on Lookout and Signal Mountains.

Pertinent climatological data are indicated in Fig. 2. Temperature deficiency is shown as the average degree-days for a 5 year period. Mean wind velocities as plotted cover a 7 year period. The upper right tabulation gives in round numbers the percentage frequency of wind velocities in 3 brackets. Velocities over 31 mi./hr. involved less than 0.5% of the total. The "star" insert indicates, on an annual basis, the percentage frequency of wind direction towards the center of the star for velocities over 3 mi./hr. The vectors total 58%, the balance of 42% agreeing with the corresponding figure in the upper tabulation.

With a normal lapse rate, pollutants escape from the valley in a very satisfactory manner, even with relatively low wind velocities. However, during the heating season, temperature inversions frequently cause objectionable air pollution. The temperature on Lookout Mountain in the early part of the day is often about 5°F. above that in the valley; and, in extreme cases, the difference is as much as 15°F. The inversions usually clear by the middle of the morning (seldom past noon) and to date there is no record of one having lasted all day. The inversion layer is usually below the tops of the mountains and at times it is below Missionary Ridge and the other lesser elevations. The cessation of the morning "blackouts" that used to limit visibility in the main part of the city to 1 or 2 blocks is evidence of improving pollution control.

Thus, climatological conditions involve a relatively mild temperature deficiency, a low mean wind velocity, a wind velocity decrease during the non-heating season, and prevailing wind directions south-southeast and north-northwest (quite favorable in moving nearly parallel to the longitudinal axis of the valley). The city is subject to temperature inversions, frequently characteristic of a valley through which a river flows.

Dustfall Determinations

Chattanooga began its fight against air pollution in the mid-twenties but not until a decade later did funds become available for a full-time job for 1 man. More than another 10 years passed before the present staff of 3 men and a secretary became possible. Dustfall determinations have been made during 3 periods since 1935 and during the past year dust determinations have been made with an electrostatic precipitator and a high velocity sampler.

Though a considerable number of dustfall stations have been operated at various times, the most useful findings

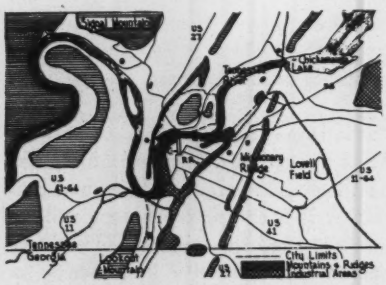


Fig. 1. Chattanooga and Environs.

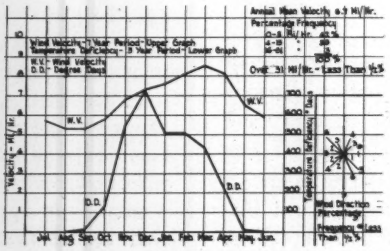


Fig. 2. Pertinent Climatological Data.

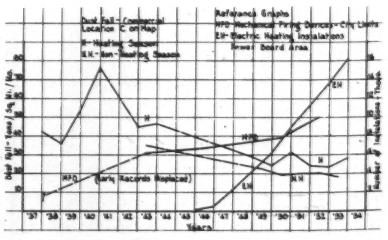


Fig. 3. Dustfall at Station "C".

have come from 4 stations. The map of the city indicates the locations as follows: "C" is in the center of the downtown business area and has been used to gage progress in a commercial location; "RR" is located immediately adjacent to the largest railroad yard and reflects pollution from locomotives; "I" is located in a small commercial area which is almost completely surrounded by an unrestricted industrial zone and indicates conditions in one of the most concentrated industrial centers of the city; and "R", located in a residential district, is useful in studying the effect of pollution from the nearby industrial area. Relatively little attention has been given the larger residential sections at greater distance from industry, many of them beyond the city limits.

Fig. 3 shows the results of dustfall determinations at Station "C" and other pertinent information. Following the first tests in 1937 there was an increase in dustfall for 3 years, but since 1940 there has been a marked decrease. Mechanical firing devices have been the major factor in the improvement in this area. The line "MFD" shows the total number of permits for mechanical firing devices that had been issued up to the end of each fiscal year. The term covers stokers and gas and oil burners for residential, commercial and industrial installations within the city limits. The line "EH" shows the total number of recorded electric heating installations at the end of each year according to the records of The Chattanooga Electric Power Board, including installations beyond the city limits.

Fig. 4 shows dustfall at Station "I". Located near this station are a brickyard, electrometallurgical furnaces, a chemical plant, coke ovens, oil mills, textile plants, a glass factory and a special industry operating the largest boiler installation in the city. With increasing activity in this area there was an increase in dustfall up to 1949, followed by a marked decrease, though there has been no drop in industry. The improvement has come through the use of mechanical firing devices along with fly ash, dust and fume control.

Results for the residential section, at Station "R" across a low ridge from the above industrial area, are shown in Fig. 5. Originally this was a very clean part of the city, as indicated by early dustfall readings, but there was a definite increase by 1949, followed by a marked improvement paralleling that in the nearby industrial area.

The greatest improvement has occurred at Station "RR", as shown in Fig. 6. The improvement from 1943 to 1950 resulted from better operation and handling of steam locomotives and (since 1950) the almost complete use of Diesel engines. (The indicated rise for 1952-3 has not been accounted for.)

Air-Borne Dust Determinations

The amount of dust in the air at breathing level has been determined during the past year in commercial and industrial areas and in certain residential districts subject to pollution from adjacent industry (most of the data having been obtained during the 1953-54 heating season). In most tests, an M.S.A. Electrostatic Sampler and a Staplex High Velocity Sampler were used simultaneously. In general, higher results were obtained with the high velocity sampler.

Recorded determinations have been classified in accordance with city zones as follows:

TABLE I
Air-Borne Dust by Zones

Zone	Dust Range mg./m.^{3}	Average Dust mg./m.^{3}
Residential	0.03- 1.62	0.35
Commercial	0.06- 1.67	0.52
Industrial (light)	0.06- 1.22	0.40
Industrial (heavy)	0.06-14.20	1.58

These data compare favorably with results reported in other cities.[1-2-3] There is danger, however, in attempting to draw conclusions from data as limited as those available. The study is continuing and it is likely that further results and conclusions will be reported in the future.

A Special Problem

Gray iron foundries are a major factor in the industrial life of Chattanooga. For the most part, they are so located as to constitute no serious local problem, though as a

(1) Cholak, J., Schafer, L. J., and Hoffer, R. F., "Results of a Five-Year Investigation of Air Pollution in Cincinnati," *Arch. Ind. Hyg. and Occupational Med., 6,* 314-325 (1952).

(2) Cholak, J., Schafer, L. J., and Hoffer, R. F., "Collection and Analysis of Solids in Urban Atmospheres," *ibid., 2,* 443-453 (1950).

(3) Cholak, J., "The Nature of Atmospheric Pollution in a Number of Industrial Communities," *Proc. Second Nat. Air Pollution Symposium,* 1952, pp. 6-15.

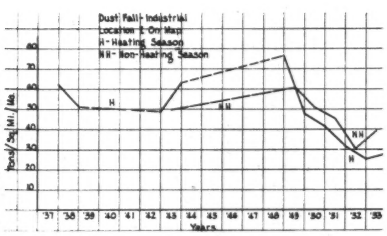


Fig. 4. Dustfall at Station "I".

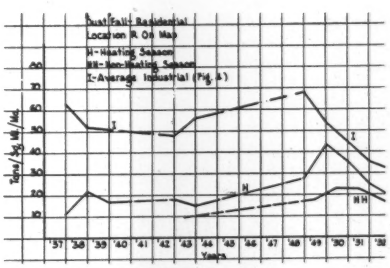


Fig. 5. Dustfall at Station "R".

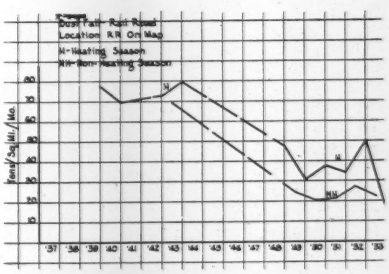


Fig. 6. Dustfall at Station "RR".

whole they make a definite contribution to over-all air pollution. Only 1 of many cupolas is equipped with a device to reduce dust and fume emission, but such equipment is under consideration by the others.

For many years a plant located slightly more than 1 mile from the heart of the city has manufactured ferroalloys in electric furnaces, with no provision for the control of fumes. This has been a major problem in the immediate neighborhood and, under unfavorable weather conditions, over a wide area at ground level. Recently the company installed additional furnaces at this location. Soon after operations were started a 75 ft. stack with a dust collector at the base was put into use. This was of definite help but did not remedy the situation. 50 ft. were added to the stack with better but still not satisfactory results. Fumes of nuisance quantity were still leaving the stack and vents in the sides of the building. It became obvious that a taller stack was required, one that would discharge the fumes at an elevation that would allow more dilution before their return to the ground. A concrete stack, 300 ft. high and 30 ft. in diameter was constructed and it has proved reasonably satisfactory in the immediate vicinity of the plant. However, the fumes still contribute to the over-all pollution of the valley, particularly during periods of low temperature inversion. The company has also been conducting investigations (both locally and through an independent research laboratory) of methods for reducing the fume burden in the gases leaving the furnace. As soon as experience with the 300 ft. stack and the research program justify, the furnaces will be moved to a new location and they will have such facilities as may be deemed necessary.

Summary

Chattanooga is an industrial city with a topography and climatology which tend to intensify the effects of air pollution resulting from the improper burning of fuels and from fumes incidental to certain manufacturing operations. Though the Bureau of Air Pollution Control and Boiler Inspection has had a slow growth and is still inadequate, due to lack of available funds, considerable progress has been made under its supervision. Atmospheric conditions have been improved as judged by visual observation and by dustfall determinations over a considerable period of time. This improvement has come about largely through the installation of mechanical firing devices and equipment for arresting fly ash and dust, through conversion to Diesel engines by the railroads, and through the rapidly expanding use of electric heating.

Recent air-borne dust tests afford useful information as to the intensity of pollution at several important locations. These tests have given results that compare favorably with those recorded in the literature for other industrial communities.

(Continued from page 202)

Oil Refineries in Los Angeles County

Appendix

Excerpt from *Rules and Regulations*, Air Pollution Control District, County of Los Angeles:

Rule 56. Storage of Petroleum Products. A person shall not place, store or hold in any stationary tank, reservoir or other container of more than 40,000 gallons capacity any gasoline or any petroleum distillate having a vapor pressure of 1.5 pounds per square inch absolute or greater under actual storage conditions, unless such tank, reservoir or other container is a pressure tank maintaining working pressures sufficient at all times to prevent hydrocarbon vapor or gas loss to the atmosphere, or is so designed and equipped as to prevent hydrocarbon vapor or gas loss to the atmosphere, by being equipped with one of the following vapor loss control devices, properly installed, in good working order and in operation:

a. A floating roof, consisting of a pontoon type or double-deck type roof, resting on the surface of the liquid contents and equipped with a closure seal or seals to close the space between the roof edge and tank wall, or

b. A vapor recovery system, consisting of a vapor gathering system capable of collecting the hydrocarbon vapors and gases discharged and a vapor disposal system capable of processing such hydrocarbon vapors and gases so as to prevent any emission to the atmosphere, with all breathing vents to atmosphere set at least 0.5 ounce per square inch greater than the setting of valves opening into the vapor disposal system and with all tank gauging and sampling devices gas-tight.

c. Other equipment of equal efficiency, provided such equipment must be submitted to and approved by the Air Pollution Control Officer.

This rule shall be effective immediately as to any such stationary tank, reservoir or other container not completed and put into service at the date of the adoption of this rule. As to all other such tanks this rule shall be effective as follows:

Class I. Any such tanks of 400,000 gallons or greater capacity used for cracked stocks, on February 1, 1954.

Class II. Any such tanks less than 400,000 gallons capacity used for cracked stocks, on August 1, 1954, except that any person owning or controlling more than one such tank shall comply with all of the provisions of this rule by May 1, 1954, as to at least 50 percent of the total capacity of such tanks not designed and controlled in accordance with this rule on the date of its adoption.

Class III. Any such tanks of 400,000 gallons or greater capacity used for any gasoline or petroleum distillate other than cracked stock, on February 1, 1955.

Class IV. Any such tanks of less than 400,000 gallon capacity used for any gasoline or petroleum distillate other than cracked stocks, on May 1, 1955.

Evaluation of The Multiple Spot Discoloration Tester

THOMAS D. PRICE
Raytheon Manufacturing Company
Waltham, Massachusetts

HANS KLEMPERER
Air Preheater Corporation
Wellsville, New York

The Multiple Spot Discoloration Tester is a device for determining the efficiency of filtering equipment by the discoloration (blackness or stain) method. It is an improved version of the discoloration tester developed at the National Bureau of Standards[1] and it was developed to provide faster tests on electrostatic air cleaners.

The discoloration method has the following advantages over other methods of testing:

1. Results are simple to evaluate—much less time required for determination of results than for either the weight or particle count method.
2. Analysis of the sample is not affected by humidity.
3. Faster in operation—can follow varying conditions in a filtering medium.
4. Provides a permanent record of results.
5. Much more sensitive to small particles than the weight method.
6. Generally accepted for efficiency measurements for electrostatic air cleaners for ventilation purposes and should be applicable to other types of electrostatic equipment.

The discoloration method was developed by the Bureau of Standards for evaluating the efficiency of filtering equipment for the United States Government. It has been effectively used in various forms for the testing of electrostatic air cleaners on atmospheric air where the average size particle is less than one micron in diameter.[2-3]

The Bureau of Standards discoloration test is based on a comparison of the discoloring or staining of filter papers by samples of gas passing through them simultaneously, before and after the cleaning device under test. If it takes 10 times the volume of gas from the clean or outlet side of the cleaning device to show the same degree of discoloration as that from a single volume of gas from the dirty or inlet side, the equipment is considered to be 90% efficient.

Most discoloration testers are of the two-spot type. One spot is obtained from the inlet to the filter and the other spot from the outlet. Techniques for obtaining these spots may vary as follows:

1. If the areas of the filter papers are different, the sampling rate, time of sampling, and the density of deposit should be equal. In practice, this may take several tries with different size papers to obtain equal stains, as the efficiency of the filter must be estimated by the operator when setting up the test.
2. If the areas of the filter papers are equal, the sampling rate may be varied to give equal discoloration for equal times of sampling. A representative sample may or may not be obtained, as the efficiency of the filter paper varies with the velocity through it.
3. If the areas of the filter papers and the sampling rates equal, the time of sampling may be varied to obtain equal discoloration. Personal judgment in estimating the original timing facilitates rapid determination of results. Also, the samples obtained may not be representative, particularly if the dust concentrations of the gas to be cleaned vary during the test.

The Multiple Tester

The Multiple Spot Discoloration Tester overcomes these disadvantages and has features which permit more reproducible results. This tester is actually 4 testers built

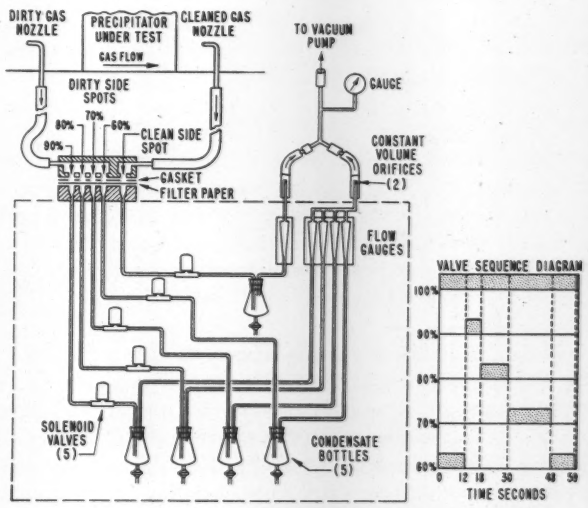


Fig. 1. Multiple Spot Discoloration Tester—Schematic and Valve Sequence Diagrams.

1. Dill, R. S., "A Test Method for Air Filters," *Trans. Am. Soc. Heating Ventilating Engrs., 44,* 379 (1938).
2. Dalla Valle, J. M., "Micrometrics," 2nd Edition, Pitman Pub. Corp., New York, N. Y., 1948.
3. Drinker, P., and Hatch, T., "Industrial Dust," 1st Edition, McGraw-Hill Book Co., New York, N. Y., 1936.

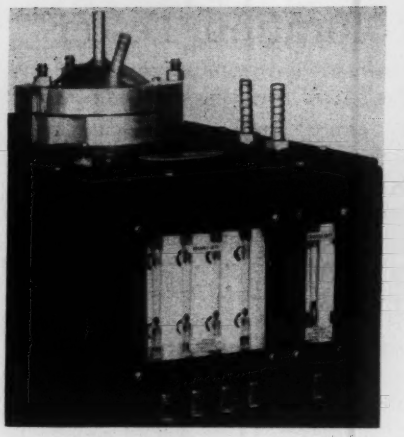


Fig. 2. Typical Multiple Spot Discoloration Tester.

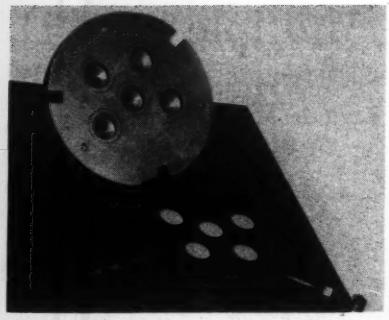


Fig. 3. Top of Multiple Spot Discoloration Tester, Showing Filter Paper Holder and Orifices.

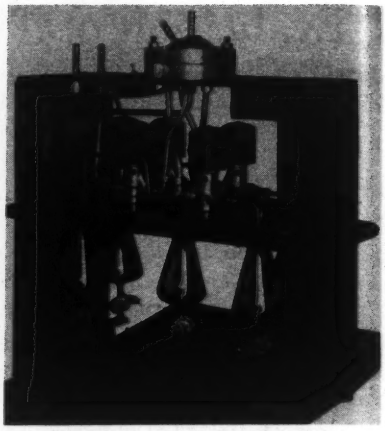


Fig. 4. Open View ➡ of Multiple Spot Discoloration Tester, Showing Arrangement of Components.

into 1 unit, using equal paper areas and constant sampling rates, and varying the timing for the tests. With pre-set timings, the discolorations are not equal, but are a definite degree of discoloration. The following timer settings are convenient:

Clean gas sample	100% of the Test Time
Dirty gas sample A	10
Dirty gas sample B	20
Dirty gas sample C	30
Dirty gas sample D	40

Variations of these timings can be made provided the sum of the four dirty spot times equals the clean test time (100%).

The principal elements of the tester are: (a) the filter paper holder; (b) electric timer; (c) solenoid valves; (d) rate of flow indicators (flow gauges); and (e) constant volume orifices. For flue gas testing an additional element was added—condensers or condensate bottles to trap condensation prior to the flow gauges. These elements are shown schematically in Fig. 1; and as packaged in a typical unit for flue gas testing, in Fig. 2, 3, and 4. The unit shown in Fig. 2 is approximately 24 in. long, 10 in. wide, and 24 in. high.

Gas flow through the tester is shown in Fig. 1. The filter paper holder is sized to accommodate a 12.5-cm.-diameter filter paper. The solenoid valves are opened and closed by cam-operated switches on a repeat-cycle timer. The flow gauges indicate the volume of sample, and the constant volume orifices are sized and calibrated for isokinetic sampling.

The timer is driven by a synchronous motor controlled by a switch on the top panel. The switch-operating cams of the timer are accurately pre-set (by means of a cycle timer) so that the solenoid valves are opened for a finite portion of the operating cycle. For heavy concentrations of particles in the gas a one-minute repeat-cycle timer is used. (For lighter concentrations this may be changed to a two-minute repeat-cycle.) There are hold-in contacts on the timer, so that after the timer is started (even though the operating switch is turned off) the timer will not stop until it has completed its operating cycle. The timer is always adjusted to start and stop during the longest time interval for the dirty gas flow (40% of the operating time.) If desired, the timer may also control the vacuum pump or an externally operated solenoid valve.

A Photoelectric Comparator, used to evaluate the degree of opaqueness of the samples collected on the filter papers, is shown in Fig. 5. Its principal components are a light source (maintained at a constant intensity by means of a built-in voltage stabilizer), a lens system, a photoelectric cell, and a microammeter. Fig. 6 shows the arrangement of a typical unit, approximately 16 in. long, 8 in. wide, and 9 in. high.

Procedure

As with any "sampling method" of testing, it is important that a representative sample be obtained. If many tests are proposed for a given installation, it may be advantageous to utilize a multiplicity of sampling nozzles manifolded together. If but a few tests are to be made, a traverse of the sampling areas would suffice. If hot gases are to be sampled, it is important that the sampling lines be warmed up to prevent condensation forming in them which would be carried to the filter paper. It is also advisable to put a filter paper in the holder and operate the unit for a few cycles to clean any foreign matter out of the lines. This will, in addition, give an opportunity to check the flow gauges to insure that all connections are tight and that equal flows prevail.

Mark a fresh filter paper lightly with pencil (from the template for this purpose) outlining the 5 sample ports, place the paper in the comparator and get the "clean" readings. (Be careful not to have the lines exposed to the light beam.) These readings are necessary as the filter paper is not sufficiently uniform to permit using a

single reading for all of the paper. It is recommended that 3 readings be taken within each of the five circles. The center circle is the "test" or cleaned gas port, and the outer circles are for the dirty gas ports (10%, 20%, 30% and 40% of the operating cycle).

After the sampling lines have been cleaned out, the measured filter paper is placed in the holder and the unit is started. The vacuum pump must maintain a pressure differential of at least 53% of one atmosphere. With this differential, the flow through the orifices is of constant volume and any change in resistance due to paper loadings, hose fouling, or changes in sampling location, will not change the rate of flow; thus, a constant volume is maintained without regulation. The flow meters will verify this.

When one or more operational cycles of the timer have been completed and the tester stopped, remove the filter paper and make an approximate efficiency determination by visual comparison. For example, if the 10% time spot is darker than the center spot, the efficiency is greater than 90%. For a measurement, place the paper in the comparator and again take 3 readings of the opacity for each of the 5 spots, recording the values and averaging them for each spot. The meter reading for the clean paper minus the reading for the paper and deposit divided by the reading for the paper and deposit has been found to be an excellent index of the amount of deposit on a given spot:

$$\text{Deposit ratio} = \frac{\mu\text{A Paper} - (\mu\text{A Paper} + \text{Deposit})}{(\mu\text{A Paper} + \text{Deposit})}$$

By substituting in this expression, the deposit ratio for each of the known efficiency spots is obtained, and it is plotted on a graph as shown in Fig. 7. The deposit ratio for the "test" or cleaned gas port (obtained from the same formula) is plotted as a straight line vertically; the intersection with the plot of the known points indicates the efficiency.

The paper (or paper and deposit) are measured by the amount of transmitted (not reflected) light. It will be noted during usage that the known efficiency points do not always fall in a straight line. This is believed due to the penetration of the filter paper by some of the particles. (Experiments are being conducted with other types of filter media, but results are not yet available.) Hard-faced Whatman No. 41 gives reasonably consistent results.

For best results, the discoloration of the filter paper should not be excessive. When the equipment is cycled too many times on a heavy concentration, the build-up on the paper is such that one opaque particle apparently covers another and the results obtained are not precise. Our experience has indicated that the time of sampling for atmospheric air or flue gas should be such that the maximum deposit ratio does not exceed 0.6.

Evaluation of The Tester

The advantages of the Multiple Spot Discoloration Tester may be listed as follows:

1. Avoids trial-and-error manipulation.
2. Avoids personal judgment.
3. Provides equal velocity (avoiding differences in efficiency of paper due to varying velocities.
4. Provides a representative sample.
5. Provides a statistical advantage of having several spots for comparison.
6. An immediate approximation of the efficiency range may be made by eye.
7. Results are confined to a single piece of paper, simplifying the maintenance of permanent records.

The multiple tester has been used very effectively in our experimental work on high temperature flue-gas cleaning equipment. Most of the testing was done where pulverized coal was the principal fuel. The dust loadings were normally quite heavy, and there was a large percentage of fine particles whose diameters were less than 10μ. Some 1500 efficiency measurements have been made with this equipment during the course of our experimental work. The speed with which measurements were made

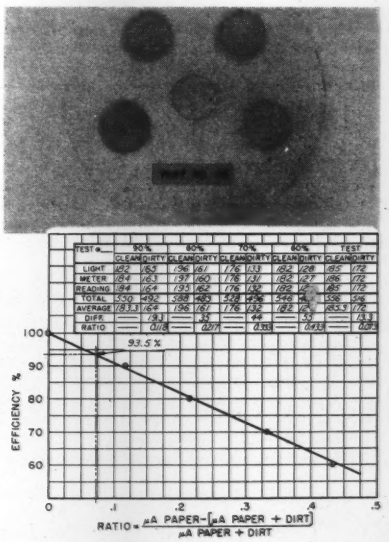


Fig. 7. Typical Test Paper, Calculations, and Efficiency Graph. ➡

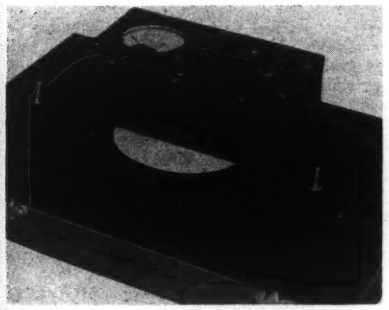


Fig. 5. Typical Photoelectric Comparator used to Measure Filter Papers.

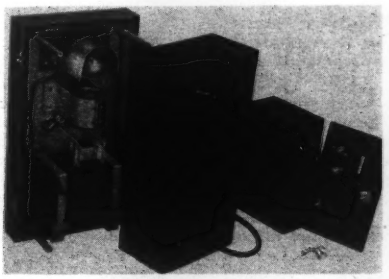


Fig. 6. Open View of Photoelectric Comparator, Showing Arrangement of Components.

was extremely helpful in studying effects of varying conditions. It was not unusual to make 8 or 10 efficiency measurements in 1 hr.

Most of the preliminary evaluation of this experimental, flue-gas cleaning equipment was made entirely with this tester. As many of the design features were incorporated, their effect on collecting efficiency was readily determined.

It was realized that final measurements of the experimental cleaning equipment would have to be made by the A.S.M.E. Test Code for Dust Separating Apparatus[4] in order to correlate the operation of our experimental equipment with other equipment. Weight measurements showed that our discoloration tester had served us well as a guide. On several occasions, simultaneous weight and discoloration measurements were made on the pilot installation at the Hell Gate Station of the Consolidated Edison Company of New York. Day to day measurements between the 2 methods varied ±4%, but the averages of measurements over a period of time were almost identical.

Summary

The construction and operation of a Multiple Spot Discoloration Tester are described. The tester can be used effectively for the testing of electrostatic air cleaners. Moreover, because of the successful application of the tester to our experimental work on flue gas cleaning equipment, we believe that it is a very useful tool for laboratory guidance as well as for rapid checking of field installations. However, the tester is not intended for use in measuring guaranteed efficiency of industrial equipment.

4. "Test Code for Dust Separating Apparatus," *Am. Soc. Mech. Engrs.*, 1941.

DISCUSSIONS OF PAPER ENTITLED "EVALUATION OF THE MULTIPLE SPOT DISCOLORATION TESTER" BY THOMAS D. PRICE AND HANS KLEMPERER

The Multiple Spot Discoloration Tester described by Price and Klemperer should be of particular interest to government air pollution engineers and I believe it warrants a careful investigation in the field to determine its possible usefulness in air pollution prevention work.

It offers a possible way of meeting the great need of a simpler method than the A.S.M.E. test code for determining dust collector efficiency and it may well give good relative information regarding emissions from chimneys that would be of value for guidance. It seems probable that enough accuracy could be obtained for useful purposes. The Ringlemann chart for smoke readings has proven very valuable, but arguments as to its accuracy are perennial. How accurate are the results obtained by the A.S.M.E. test code for dust-separating apparatus? It is its own standard.

In listing the principle elements of the multiple tester, the authors refer to "constant volume orifices." Might not this better be "constant volume nozzles"? The constant volume feature as used would not be obtainable with what is ordinarily termed "thin plate orifices." It would be obtainable with a converging nozzle cut off at the throat. Did not the "orifices" have converging entrances? If the authors would give more explanation as to the reason why the "deposit ratio" formula was found to be an excellent index of the amount of deposit, it would be helpful to the reader.

The authors are to be congratulated for the paper.

J. F. Barkley
Bureau of Mines
Washington, D.C.

This type of test equipment was used by Air Preheater Corporation and Raytheon Manufacturing Company in studying the performance of an experimental precipitator at our Hell Gate generating station on a boiler burning pulverized coal and/or oil.

Judgment must be used in its application but, properly used, a good degree of reliability may be expected in the quick determination of dust-collecting efficiencies by spot-discoloration tests.

Our staff made several simultaneous performance checks, utilizing the Brady thimble traverse technique, in accordance with the A.S.M.E., Test Code for Dust Separating Apparatus. Reasonably good agreement was obtained, on the average, when determining performances in the 90% efficiency range.

Much can be said in favor of multiple spot blackness testers, particularly in tests of dust collectors under varying conditions.

However, while a quick determination of efficiency is rendered, we must fall back on standard testing procedure for the highly essential basic information on dust loading/ft.^{3} in the gases entering or leaving the collector. The field of usefulness is therefore primarily as a comparator of inlet versus outlet dust obscuration ratios.

John J. Grob
Consolidated Edison Company
New York, N. Y.

The subject matter of this paper is of particular interest to us and provides an opportunity to advance some views we have entertained concerning appropriate methods for evaluating efficiency of gas-cleaning equipment and for measurement of emission rates. We have long emphasized the distinction between coarse, heavy particles which are invisible until they become deposited as dust fall, as against very fine, weightless particles (like fuel smoke or metallurgical fumes) which scatter light and discolor surfaces but contribute insignificantly to dust fall—a distinction which is important in a consideration of methods for measurement of air pollution intensity at ground level.

It is entirely logical to apply the same considerations in the measurement of stack emissions as well as in a determination of the efficiency of a gas cleaner but we should not fall into the error of assuming that the method of determining weight concentration or weight rate of emission is in any way a substitute for one which expresses results in terms of staining potential, i. e., light scattering. That is, it would not be logical to seek even a rough correlation between the two types of measurement. The correlation found by the authors is therefore an indication only of the fact that uniform combustion conditions prevailed during their studies, i.e., that the ratio of coarse to fine particles was constant.

The same considerations apply to and are recognized in the testing of air cleaners for ventilation systems, where some types of cleaners are evaluated by weight efficiency methods and others (like electric precipitators and woven fabric filters) on the basis of light scattering, i.e., filter paper staining potential.

A good illustration of the value of these conceptions is in the testing of the efficiency of various devices for cleaning open hearth furnace stack gases. In some recent studies of this nature, tests were run on pilot installations of a number of dust collectors and the performance of each reported in terms of weight efficiency. However, the true criterion applied to these investigations was the appearance of effluent gases, since it had been observed[1] that "the outlet dust loading must be down to 0.05 gr./ft.^{3} to give a clear stack. Above this loading, a by-stander cannot tell whether there is a cleaning unit on the stack or not." Since, in this instance, the real criterion of performance was light scattering or staining potential, it would have been logical to measure efficiency on this basis (a measurement which could readily be made by the multiple tester described by the authors of this paper or by the Dill Dust Spot Tester.)

This could also be readily determined with identical results by the methods described in our paper[2], wherein the concentration of haze or smoke in stack gases is evaluated by measurement of light transmission through the paper stain, and the quantity of deposit is expressed in terms of the computed optical density. We suggested that the emission of smoke or haze can be conveniently expressed in the units Coh-ft.^{2} per minute.

For illustration, a certain iron cupola equipped with a low-draft-loss mechanical collector, tested by us in recent months, discharges solids in the clean gas stream at a rate of 50 lb./hr. and haze at rates ranging from 17,000 to 46,000 (averaging 23,000) Coh-ft.^{2} per minute. Another similarly equipped cupola in another plant discharged 50 lb. solids/hr. and haze potential at rates ranging from 17,000 to 40,000 (averaging about 25,000) Coh-ft.^{2} per minute. The first figures described the contribution of the cupolas to dust fall in the neighborhood, the second describes the visible discharge which contributes to visible haze and surface discoloration. In other words, two distinct qualities are described by the two measurements and they are unrelated to each other.

We would comment on the author's statement about filter paper efficiency in relation to filtration velocity. It is known that filter paper efficiency is related to velocity when it is evaluated by means of highly sensitive, light-scattering instruments and where the test is confined to the very early stages when the filter paper is still clean; but when efficiency is evaluated in terms of staining potential, which of course implies a certain degree of plugging of filter paper pores during the test, the filtration efficiency is for practical purposes independent of filtration velocity.

One other point needs correction—the author's reference to the need for isokinetic sampling. The particles which contribute to the optical effect observed as staining of a filter paper have practically no inertia and are sampled quantitatively from a gas stream regardless of the relative velocities in the sampling nozzle and in the gas stream.

We are grateful to the authors for their interesting and worthwhile presentation.

1. Vajda, Stephen, "Open Hearth Dust Control," **Iron Steel Engr., 29, No. 7,** 111 (1952).
2. Hemeon, W. C. L., Haines, G. F., and Ide, H. M., "Determination of Haze and Smoke Concentrations by Filter Paper Samplers," **AIR REPAIR, 3,** No. 1, 22 (1953).

W. C. L. Hemeon
Mellon Institute
Pittsburgh, Pa.

A "two-spot" discoloration tester with a built-in photoelectric comparator was briefly described in R. S. Dill's original paper[1].

The physical embodiment of this description is now available commercially. It eliminates the objections to the "two-spot" method which are set forth in Price and Klemperer's paper.

In Fig. 1, light source (A) is mounted in a ventilated housing between the two condenser lenses (B) so that beams of light pass through the two condenser lenses and the two sampling papers (C) and are received by the photocells (D). The position of the light source is adjustable so it may be moved sufficiently to compensate for initial differences in the translucency of the sampling papers. The outputs of the two photocells are connected "bucking" through the galvanometer (E) thus indicating any relative change in the translucency of the two sampling papers. The sampling rate through each paper is individually controlled by needle valves (F) and is individually indicated on flowmeters (G). Both samples are drawn by a single portable vacuum pump (H).

The complete instrument is packed in a carrying case 17 in. long x 18 in. high x 12½ in. wide and weighs only 38 lb. Fig. 2 is a photograph of the complete machine.

There are at least three separate operating techniques each with its advantages for different operating circumstances.

The technique most commonly used is particularly adapted to the general testing and evaluation of electronic air cleaners using only the natural contamination in the ventilating air stream as an aerosol. To run a test of this type, first install sampling lances in the duct, one upstream and one downstream of the filter to be tested. Then, install clean sampling papers in the receptacles and with the light source "on," adjust its position so the galvanometer reads "zero." This is a

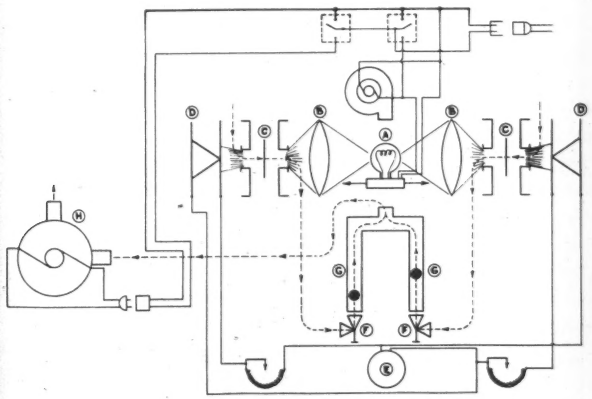


Fig. 1. Schematic Diagram of the Dill Dust Spot Tester.

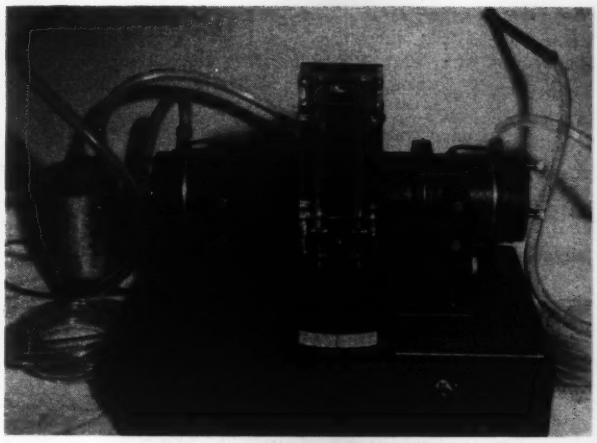


Fig. 2. The Dill Dust Spot Tester.

preliminary balance. Start pump and adjust sampling rates to about the center of the flowmeters. This will pull the sampling papers snugly against the apertures and introduce a very slight concavity in the paper. Again adjust the position of the light source to compensate for the motion of the paper due to air flow. Now observe the galvanometer needle and adjust the individual sampling rates to values that maintain a "zero" reading on the galvanometer. This balance should be maintained without readjustment from 3 to 10 minutes (depending on dirt loading). At this point the sampling rates, indicated by the interpolation of the flowmeter readings from the calibration chart will determine the efficiency.

$$\% \text{ Efficiency} = \frac{(Q_1 - Q_2)}{Q_1} \times 100$$

Where Q_1 = sampling rate downstream
Q_2 = sampling rate upstream

A second technique especially adaptable to acceptance testing of filtering devices is to pre-set the sampling rates to values representing the specified efficiency. Then if the galvanometer needle swings to the left the device under test exceeds the specification and is acceptable. If the needle swings to the right, the device is somewhat less efficient than specified.

A third technique involves the addition of a second vacuum pump to the instrument so that each sampling tube may be individually started or stopped without interfering with the rate on the other tube. This technique is based on equal sampling rates over varying times. It is particularly adaptable to conditions where the contaminating aerosol is comprised of an appreciable quantity of relatively large or heavy particles which might settle out in the sampling tubes at different rates if the flow in the tubes were unequal. The clean papers are balanced as before and the two sampling rates adjusted to be equal. Zero time is taken with the galvanometer needle on zero. With both sampling tubes operating, the time required for the needle to swing a predetermined reading to the left is noted. When this reading is reached, the upstream sampling pump is stopped and the time required for the needle to recover and then swing a predetermined reading to the right is noted. The upstream pump is again started and the time required for the needle to recover to zero is noted.

$$\% \text{ Efficiency} = \frac{T_2}{T_1 + T_2 + T_3} \times 100$$

Where T_1 = initial run of both pumps
T_2 = operation of downstream pumps
T_3 = final run of pumps

This instrument has been used primarily on ventilating air cleaners with or without synthetic contamination. The test results have shown a high degree of reproducibility on air-borne contamination over as wide a range of dust loading as might reasonably be found in ventilating systems.

---

[1] Dill, R. S., "A Test Method for Air Filters," *Trans. ASHVE, 44,* 379 (1938).

George F. Landgraf
Trion, Inc.
McKees Rocks, Pa.

(Continued from page 188)

Air Pollution Control on The C. N. R. R.

the firebox door end. When lighting the burner by placing a small piece of lighted, oily waste at the nozzle, crack the blower or use the shop blower to guard against blow-back. Adjust burner to clear flame as quickly as possible after lighting and point flame of burner directly at top arch brick. At no time should the flame be directed at the fuel bed. As the fuel bed is gradually ignited, volatile constituents and particles of carbon are released and pass through the burner flame which burns them before leaving the firebox.

After the fuel bed has been properly ignited and the fuel is in a coke condition, the firebuilder removes the burner, and then places a suitable bank in the firebox over the bare spot in the center of the grates. The rate of ignition of this center bank will be very slow and there will be no violation of smoke regulations, the smoke density not exceeding No. 1 Ringlemann.

Some firebuilders have complained bitterly about the amount of coal they were required to shovel to line the firebox on large engines. To avoid this complaint, we built a triangular box, with side dimensions of 8 in., 8 in., and 7 in., each side being 7 in. deep. This hollow, triangular box is fitted with an offset handle and it can be held in position on the distributing plate with very little effort to distribute coal for a bank, using the stoker if steam is available on the engine. If the engine is cold, the burner may be used to raise the steam pressure to a point where the stoker can be used. The heavy coke fire (from the horseshoe bank) is an asset to the engineman taking charge of the locomotive on the shop track because it eliminates the necessity of building a heavy fire and makes it possible for him to operate through smoke-restricted districts without violating smoke bylaws.

Brick Arch

It has been our practice to seal or place the brick arch tightly against the front sheet on all yard and transfer engines that are required to work continually in smoke-restricted areas. With the open or spaced arch, smoke released from the fuel bed has a direct outlet through the flues to the atmosphere. We have found that the sealed arch assists greatly in controlling the amount of smoke emitted from locomotives.

Overfire Jets

Over the entire system, hand-fired engines are equipped with overfire jets of various makes. Two makes (the TZ and what we commonly refer to as the Bazooka) are located on the sides of the firebox, three jets on each side, with those on one side staggered in relation to those on other side. Another type of jet extends down the boiler head and through the top of the firebox door ring. The purpose of overfire jets is to create the necessary turbulence that will permit the burning of the gases as they are released from the fuel bed.

On all stoker-fired engines, firebuilders, hostlers and locomotive firemen are taught to use the stoker jets as a means of controlling smoke while operating in restricted areas.

Draughting of Locomotives

The draughting of locomotives is a most important feature in any smoke abatement program. Therefore, we should constantly be on the look-out for blocked-up flues, slagged flue sheets and air or steam leaks around or in the smokebox. Nozzle bars, grate openings and air space between the firebox foundation ring and the ashpan coping should be inspected. On all road engines, we have installed air-deflector plates between the rapper shell and ashpan coping. With this arrangement, we get an even flow of air underneath the entire grate area, the fuel consumption descreases and the smoke hazard is reduced.

Everyone will agree that without proper maintenance of equipment, any smoke abatement program will fail. We are continually striving to improve the draughting and maintenance of our locomotives, not only to improve the control of air pollution, but also to improve on the general performance of the locomotives.

Quality of Coal

If we are to operate in territories where rigid smoke abatement regulations are in effect, then a good quality of fuel should be supplied in order to assist our men in the observance of these regulations.

Labor Conditions

I believe that we are all agreed that experienced and qualified workmen are one of the most important requirements for a good performance in any railway smoke control program. Railroads, like all other industries during the past few years, have had very heavy labor turnover, necessitating the training of new employees. A recent survey in one of our terminals revealed that of 15 firebuilders there was only 1 employee with 1 year's service, and that 105 new firemen were employed in 1 year. With such a turnover and with roughly 250 terminal points on our system, I believe you would readily agree that it would be almost impossible to entirely avoid smoke violations. However, taking the number of observations made by smoke supervisors, our percentage of violations for a 2-month period was less than 1%.

Educational Program

A definite program pertaining to smoke control should be followed if we are to succeed in our efforts to have an outstanding performance in smoke abatement. The features I have covered in this paper have been brought to a successful conclusion through trial and error, study and research, and we are now in a position to impart this information to our employees through bulletins, audio-visual education, lantern slides, lectures, etc., and in addition, we are constantly talking smoke control to enginemen, firebuilders, engine watchmen, hostlers, work equipment men and others who in any way are in a position to improve our smoke control performance. If we do these things, I firmly believe that in time all will become smoke control conscious and that our program of air pollution control will improve.

The Use of an Impingement Baffle Scrubber in Gas Cleaning and Absorption

ROBERT KOPITA
Peabody Engineering Corporation
New York, N. Y.

Wet scrubbing of industrial gases, to accomplish the fine cleaning required by today's industry, has been improved over many years. Among the various devices used have been spray, packed, and tray type towers. All these devices depend on the impingement method of gas cleaning.

The earliest attempt to wet scrub gases was the use of an open spray tower in which water or another scrubbing liquid was sprayed counter current to the flow of the gas. These towers operate on the probability of collision between droplets of water and dust particles. However, even in the densest spray zones, the distance between water droplets is many times the size of the particles.

Spray tower performance was improved by installing baffles, thus providing wetted surfaces for the particles to impinge against and affording greater opportunity to be trapped in the scrubbing liquid.

Filling the tower with packing further increased the chance of contact between particles and scrubbing liquid by subdividing the gas into many small streams which impinge against the wetted surface of the packing.

Tray type towers subdivide the gas into many small streams, thus directing the gas more effectively against a target and resulting in more efficient use of energy.

Impingement Baffle Plate Scrubber

This paper will confine itself to a discussion of the impingement theory of wet gas cleaning, and its application in a specific type of perforated Impingement Baffle Plate Scrubber developed by my company.

The basic action of an impingement type scrubber can best be illustrated by considering the lines of gas flow around an obstacle as shown in Fig. 1. As the high velocity, dust laden gas stream approaches the obstacle, it tends to be deflected by the body; the dust particles, however, will tend to continue in a straight line and be collected on the surface of the target (by virtue of higher inertia).

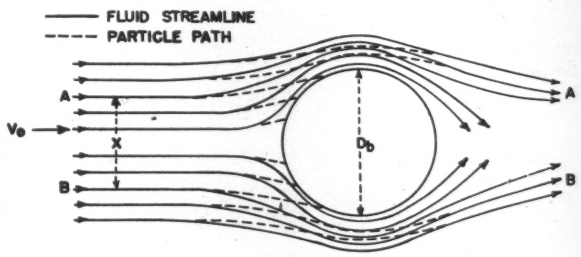


Fig. 1. Impingement Separation.

The distance that a particle can cut across the stream lines flowing around a target may be called the stopping distance, which may be expressed as

$$S = \frac{D_p P V_i}{18 u}$$

All the particles that were initially between "A" and "B" should be collected on the body. It has been shown by Sell[1], and by Langmuir and Blodgett[2] that target efficiency should be a function of the group $\frac{U_t V_o}{G_l D_b}$ (the separation number). This plot for various types of targets is shown in Fig. 2.

In these expressions,

D_p = diameter of particle
D_b = representative dimension of body impinged upon
G_l = local acceleration due to gravity
P = fluid density
S = stopping distance across streamlines
U_t = terminal settling velocity of particle
V_i = initial velocity of particle
V_o = average velocity of particle laden gas
U = fluid viscosity

The designer of an impingement type scrubber should endeavor to increase the separation number, or reduce the

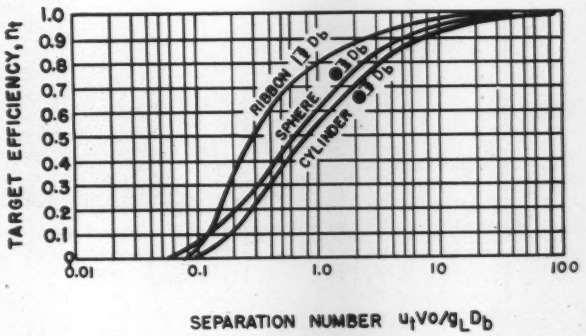


Fig. 2. Target Efficiency of Spheres, Cylinders and Ribbons.

1. Sell, W., *Forsch. Gebiete Ingenieur, 2,* 308 (1931).
2. Langmuir and Blodgett, *U.S. Army Air Force Technical Report* No. 5418, Feb. 19, 1946.

particle stopping distance. For a given gas-solids system, several changes may be made in equipment that will increase efficiency; and to implement these changes, a properly designed scrubber should have these basic actions:

1. Subdivision of the gas in many small streams,
2. Directed impingmement of the gas stream against water droplets or wetted targets, and
3. Close contact between gas and liquid to insure adequate cooling of the gas and absorption of undesirable gaseous components.

The Impingement Baffle Plate utilizes all of these basic principles in cleaning gases flowing through the scrubber.

Operation of this scrubber may best be explained by tracing the path of the gas (Fig. 3). Gas enters the lower section of the scrubber and rises through a zone of spray, usually water, created by a group of low pressure sprays. These sprays humidify the gas and strip it of coarser dust particles. The gas is now prepared for intensified cleaning action during its passage through the impingement baffle plate stage, which is flooded with water or other scrubbing liquid during the cleaning process. The plate consists of two parts:

1. A perforated sheet having from 600 to 3,000 holes/ft.^{2}, and
2. The impingement baffles above the sheet, a baffle being located directly above each perforation.

The action of the plate is illustrated in Fig 4. The mixture of gas, liquid droplets and dust particles attains a high velocity (in order of 100 ft./sec.) while passing through the plate. This increase in velocity is a function of pressure drop utilized.

Each high velocity jet is shot against a baffle directly above each perforation. Since each baffle is located at the vena contracta of the jet, the gas stream strikes the baffle at the moment of its greatest velocity, giving the highest target efficiency for the pressure drop through the perforation.

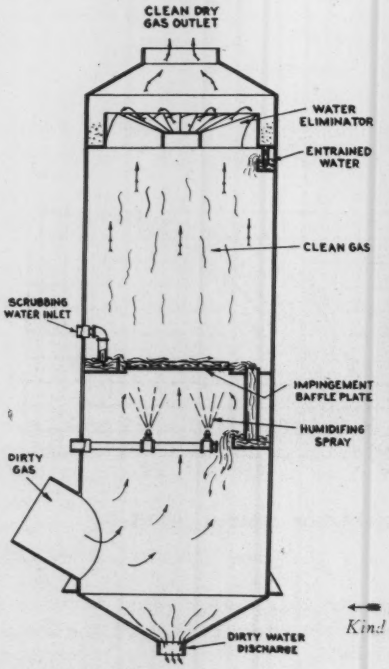
Additional impingement occurs during the passage of the gas between the perforated sheet and the baffle assembly. As the jet flows up through the plate perforation it forces the scrubbing liquid aside. This liquid tends to flow back under the baffle and encounters the high velocity gas passing through the orifice. Droplets are ripped from the liquid; and since these liquid droplets start from rest, they are overtaken by some of the rapidly moving dust or liquid particles in the gas, and thus pick up a portion of the particulate matter in the gas.

The gas on leaving the baffle comes in close contact with the blanket of liquid maintained on the plate. This results in a highly efficient mass transfer device. Any scrubber of this type that is designed for cleaning will cool the gas and/or absorb specific gas components if supplied with adequate and proper scrubbing liquids.

The scrubbing liquid enters through the liquid inlet above the top plate, flows across the plate, down through a combination drain and liquid seal, flows across the stage below, and finally leaves through the discharge pipe in the bottom.

Variables

Gas cleaning involves a number of variables; hence it is not to be expected that a simple formula to cover any gas cleaning problem can be presented. The extent of particulate matter removal from a gas by a given im-



← *Fig. 3. Flow of Gas and Liquid in This Kind of Scrubber.*

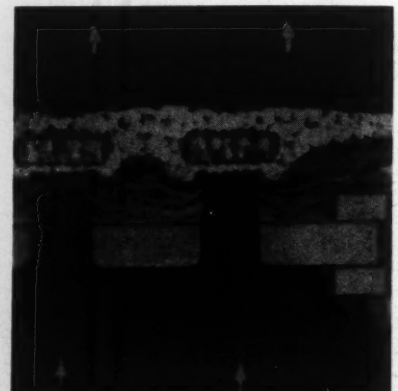


Fig. 4. Diagrammatic Illustration of Impingement Baffle Plate Showing Gas and Liquid Flow.

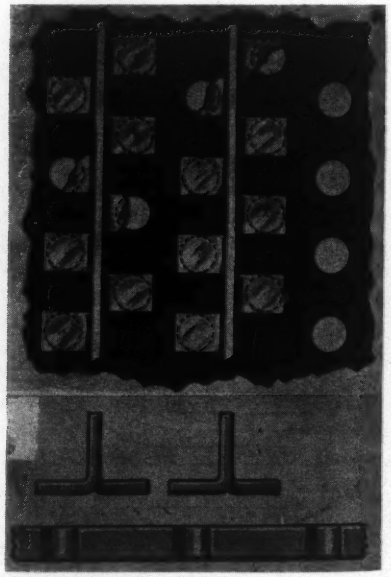


Fig. 4a. Impingement Baffle Plate Showing Arrangement of Perforated Sheet and Baffles.

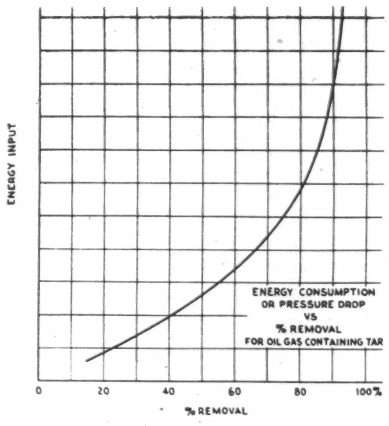


Fig. 5. Energy Input vs. Performance of a Single Impingement Stage.

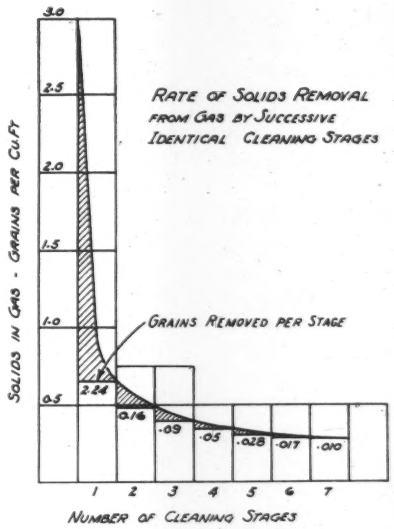


Fig. 6. Reduced Rate of Energy Utilization by Successive Identical Stages.

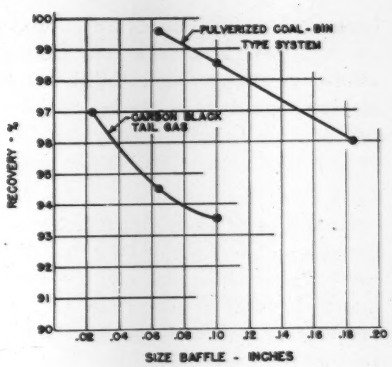


Fig. 8. Efficiency vs. Target Size.

pingement baffle type of scrubber is dependent on the target efficiency. Changes made in either the gas-solids system or the scrubber that will change the separation number $\frac{U_t V_o}{G_1 D_b}$ will affect the removal of particulate matter from the gas stream. A brief description or evaluation of the factors involved follows:

1. V_o, which represents the velocity of the gas through the plate perforations, is also a direct measure of energy input; thus the efficiency of scrubbing will increase with the energy input. However, after a certain amount of energy has been supplied, the efficiency of utilization may fall off. This is shown graphically in Fig. 5 which is a plot of velocity or energy input vs. percentage removal and shows the performance of a single plate stage scrubber while cleaning an oil gas containing tar. Energy employed beyond a certain value results in little additional cleaning; and it is this decline in efficiency of energy utilization that limits the performance of most cleaners.

The maximum amount of solids removal to be expected from a scrubber employing a series of identical cleaning stages is shown in Fig. 6. From this curve it is evident that there is a limit to the number of identical cleaning stages that can be economically employed.

2. U_t, which represents the terminal settling velocity of the particle to be removed, is also a measure in part of the particle mass.

Water vapor can be condensed around finer particles to increase their mass so they become easier to remove. This method has proved particularly valuable in cleaning hot gases and gases having a high dew point.

Another way in which the suspended matter may be conditioned is by agglomeration (combining several particles into a single larger particle). Agglomeration may be caused by violent agitation of the gas stream such as occurs in passing through a blower or a restriction. It also occurs during the passage of gas through an electrostatic field. Gas passed through an orifice or a venturi often results in agglomeration of particles.

Practical use of agglomeration may be made in cases where it is possible to locate the scrubbing element following a blower or an electrostatic precipitator, or where a venturi stage can be incorporated into the scrubber, as shown in Fig. 7.

3. D_b represents the size of the body impinged upon. The size of the baffles used with the impingement baffle plate may be varied; and Fig. 8 shows the effect of target or baffle size on cleaning efficiency. However, from a practical manufacturing viewpoint, a 1/16 in. baffle seems to be the minimum size that should be used.

Applications

The above factors are used simply to guide the design of pilot installations which are set up to study new prob-

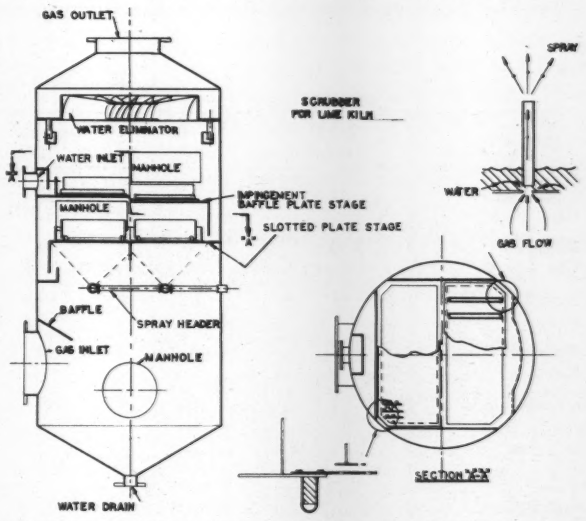


Fig. 7. Combined Venturi Aspirating Slot and Impingement Scrubber.

lems in cleaning. The importance of proper evaluation of these factors (attainable only through pilot plant installations) is amply illustrated in the successful application of these scrubbers in the reduction of atmospheric pollution in the vicinity of many industrial plants. Several typical applications are shown in Table I.

Lime Kilns

Gases vented from rotary lime kilns in many paper mills contain up to 15 gr. of dust/ft.^{3} of gas. The discharge of these uncleaned gases can create an unnecessary dust nuosance. Our combination venturi slot and impingement plate scrubbers are operating in many mills collecting dust formerly lost. The dust is collected as a warm slurry and is reused in the paper-making process. The scrubber achieves over 97% recovery, with the amount of dust in the discharge reduced to less than .3 gr./ft.^{3} of gas.

Pyrite Roasters

The roasting of pyrite and other sulfur bearing ores results in the discharge of SO_2 to the atmosphere. In order to eliminate a nuisance and to recover metallic values, these gases are being cleaned and converted to sulfuric acid. The scrubber, in addition to cooling the gases, removes better than 99% of the solid material leaving the roaster. In many cases the residual dust in the gas leaving the scrubber amounts to less than .03 gr./ft.^{3} of gas.

Blast Furnaces

A difficult gas cleaning problem, both in volume of gas handled and difficulty of cleaning, occurs in the operation of blast furnaces. In normal blast furnace practice, approximately 5 gr./ft.^{3} of dust leave the dust catcher but there are peaks of 20 to 25 gr./ft.^{3} during furnace slips.

The greater percentage of solids in blast furnace gas is dust entrained in the gas during its passage through the furnace charge. In smaller amount are particles formed by the vaporization of alkalies in the furnace charge.

As the gases pass upward through the furnace, the vaporized alkalies condense, forming particles that are in the submicron size range and are classified as fume. Scrubbers in typical basic iron furnaces where the fume loading is normal produce residual loading of .05-.06 gr./ft.^{3}, an efficiency of 99%.

Scrubbers are in operation on furnaces producing silvery iron in a 10 to 15% silicon range. Due to the extremely high temperature in the reduction zone, this gas carries a very high amount of fume. Although there are only a few furnaces in the country making this type of iron, a considerable amount of work has been done on cleaning the gas. While the residual loading is high, it is all fume; the iron ore and coke dust have been removed and the gas can be satisfactorily burned under boilers.

Pulverized Coal

In the operation of bin systems for firing pulverized coal, air vented from storage bins in many cases contains up to 1 gr. coal/ft.^{3} Scrubbers installed on these vents have reduced the amount of pulverized coal in vented air to .01 gr./ft^{3}3, an efficiency of 99%.

Carbon Black

Another difficult gas cleaning problem occurs in the manufacture of carbon black. In normal furnace operation, natural gas or oil is burned in a deficiency of air, producing large quantities of carbon. This carbon black is passed through electrical precipitators followed by high efficiency cyclones. Although the over-all efficiency of the electrical precipitator and cyclone combination is very high, in some cases the vented gas may contain up to 1 gr. of carbon black/ft.^{3}

Scrubbers are now in operation in 6 carbon furnace plants. Each scrubber is designed to handle a gas volume of 40,000 cfm. and to reduce the residual carbon black content of the gas to less than .05 gr./ft.^{3} The scrubbing liquid can be bled from the scrubber and utilized in the process, thereby preventing discharge of waste to streams.

(Continued on page 232)

TABLE I
Applications of Impingement Baffle Scrubbers

Service	Inlet Gr./ft.^{3}	Gr./ft.^{3} Outlet	Removal %	Capacity Ft.^{3}	Scrubber Diameter	Remarks
Lime Kiln Gas	15	.3	98	30,000	10′-0″	Rotary Lime Kiln-Paper Mill
Roaster Gas	30	.03	99	24,000	10′-6″	Cleaning and cooling gases containing up to 14% SO_2
Blast Furnace Gas	5	.05	99	120,000	20′-0″	Cleaning gas from blast furnace—basic iron
Blast Furnace Gas	5	.8	80	50,000	12′-0″	Cleaning gas from blast furnace—silvery iron
Carbon Black	1	.05	95	60,000	11′-6″	Cleaning tail gas in carbon black plant
Boiler Flue Gas	.5	.03	94	8,000	7′-0″	Combined scrubbing and absorption of SO_2. 99.85% removal of SO_2
H_2S Removal				7,000	7′-0″	99.9% removal of H_2S from gases vented to atmosphere

Filtration of Radioactive Aerosols By Glass Fibers*

A. G. Blasewitz and B. F. Judson
Hanford Atomic Products Operation
General Electric Company
Richland, Washington

The waste gases emitted from production and laboratory processes in the Hanford plants operated by the General Electric Company for the Atomic Energy Commission contain radioactive fission products which could result in the potentially hazardous contamination of the areas surrounding the plants if they were discharged directly to the atmosphere.[1-2-3] In accordance with the strict safety and health physics policies existing at the various AEC sites, considerable efforts have been expended to prevent any widespread contamination by either radioactive gases, such as I^{131}, or by radioactive particulate matter suspended in the stack gases.[4-5] This paper represents the final report of an extensive program undertaken at the Hanford Atomic Products Operation to develop a means for the efficient removal of sub-micron particles from the contaminated gas streams.[6]

The design specifications to be met in the filtration of radioactive aerosols are more rigorous than those of the ordinary commercial collector. Furthermore, since the collection of large amounts of contaminated material in one place is inherently dangerous, the stringent requirements of AEC safety policies restrict considerably the possible methods by which the air pollution problem may be solved. A brief summary of the specifications which were established as the development and design goals for the Hanford process air filters is presented in Table I. It is evident that the more common types of commercially available dust collectors, such as cyclones and scrubbers, fail to meet one or more of these specifications.

An expedient solution to the problem of removing radioactive aerosols from the Hanford waste gases was a fixed-bed filter consisting of successively finer gradations of sand, placed in a large underground container, and suitably equipped with air distributors, plenum chambers and duct work.[7-8-9] The first fixed-bed filters of this type were installed in the fall of 1948. The characteristics of the units agree well with the specifications in Table I and the filters have performed in a highly satisfactory manner to the present time. The sand filters, however, are bulky and expensive, and their measured efficiency (in the order of 99.7 per cent) is not adequate for the more highly contaminated gas streams.

Table I
AIR FILTER SPECIFICATIONS

1. A collection efficiency of 99.99 per cent for submicron particles present in low concentrations.
2. A minimum initial flow resistance commensurate with the desired collection efficiency.
3. A minimum of maintenance in the continuous operation of the unit.
4. A life expectancy in terms of years.
5. Containment of the collected radioactive materials in a manner that will not. cause a subsequent disposal problem.

It was suggested by Lapple that the substitution of glass fibers for sand might lead to some improvements in filter design and operation.[10] Since the results of preliminary tests were favorable, an extensive investigation of the filtration characteristics of glass fibers was initiated. The program was divided into three primary studies consisting of: (1) the correlation of collection efficiency under start-up conditions with the superficial velocity of the gas stream, and the bed depth and packing density of various types of glass fibers; (2) the correlation of flow resistance under start-up conditions with the same variables; and (3) a study of the expected service life of the glass fiber filters. Complete details of the experimental procedures and graphs of all the data obtained on the various types of glass fibers are presented in Reference No. 6.

The Collection Efficiency of Glass Fiber Filters

The efficiencies with which glass fiber beds remove suspended particulate matter were measured under field con-

(1) "Waste Disposal Symposium," *Nucleonics,* vol. 4, No. 3, pps. 9-23 (1949).
(2) "Ionizing Radiation Material as an Air Pollutant," *Nucleonics,* vol. 6, No. 6, pps. 70-71 (1950).
(3) Parker, H. M., "Review of the Stack Discharge Active Particle Contamination Problem," General Electric Co., Hanford Atomic Products Operation, Document No. HW-9259, (3-22-48).
(4) "Handbook on Aerosols," Atomic Energy Commission, Washington, D. C. (1950).
(5) "Handbook on Air Cleaning," Atomic Energy Commission, Washington, D. C. (1952).
(6) Blasewitz, A. G., Carlisle, R. V., Judson, B. F., Kurtz, E. F., Schmidt, W. C., and Weidenbaum, B., "Filtration of Radioactive Aerosols by Glass Fibers," General Electric Co., Hanford Atomic Products Operation, Document No. HW-20847, Parts I and II, (4-16-51) (available from the Office of Technical Services, Department of Commerce, Washington 25, D.C.).
(7) "Waste Disposal Symposium," *Nucleonics,* vol. 4, No. 3, p. 11 (1949).
(8) Work, J. B., "Decontamination of Separation Plant Ventilation Air," General Electric Co., Hanford Atomic Products Operation, Document No. HW-11529 (11-10-48).
(9) Lapple, C. E., "Stack Contamination, Interim Report," General Electric Co., Hanford Atomic Products Operation, Document No. HDC-611 (8-6-48).
(10) Lapple, C. E., "Stack Contamination, Interim Report," General Electric Co., Hanford Atomic Products Operation, Document No. HDC-978 (1-25-49).

*Paper presented at APCA Annual Meeting, Chattanooga, Tenn., May 3-6, 1954.
Paper also presented at Annual Meeting of the American Institute of Chemical Engineers, St. Louis, Mo., Dec. 13-16, 1953.
Published in *Chemical Engineering Progress,* Jan. 1955.

ditions by employing as a testing medium the radioactive aerosol discharged from one of the plants' process-cell ventilation systems. Particle size determinations made with a Modified Cascade Impactor indicated that the radioactive particulate matter in the process-cell air was predominantly in the sub-micron range (experimental values of the geometric mean particle diameter varied from 0.2 to 0.7 micron). No attempt was made to determine the size distribution of the uncontaminated particles since the efficiency tests were to be based upon radioactivity measurements. Other studies revealed that the dust loading of the air entering the process cells was 0.01 and 0.02 grains per thousand cubic feet, and that the particle concentration of the effluent air was in the order of 0.2 and 0.4 grains per thousand cubic feet. The figures indicated that the preponderance of both the contaminated and the uncontaminated particles of the gas stream originated in the process cell area. Particle concentrations of this magnitude are sufficiently low to make filtration by a fixed-bed highly attractive in terms of expected filter life.

It should be noted that the experimental results presented in this paper are directly applicable only to systems wherein the size distribution and concentrations of the suspended particulate matter are comparable to those of the testing media. In cases where a significant difference in particle size distribution exists, for example, the collection efficiency of a given fibrous may be appreciably different.

Experimental Equipment

The supply of process-cell air employed in testing the glass fiber units was withdrawn from a sample port located in the main duct system connecting the process cells and the plant sand filter. The air stream was drawn through the experimental glass fiber bed, metered in an orifice section, decontaminated in a standard Chemical Warfare Service box-type filter (rated efficiency of 99.9 per cent), and exhausted to the atmosphere through a steam-operated evacuator. A typical unit in which the fiber glass was tested consisted of a piece of large diameter (between 4 and 10 inches) pipe flanged at both ends and provided with pressure taps near the top and bottom for flow resistance measurements. Above the bottom pressure tap a screen was welded inside the main body to serve as a support for the filter bed. The fibrous glass was then packed to the desired density and depth.

During the course of an efficiency determination, continuous samples of the gases upstream of and downstream from the filter unit were withdrawn from the test stream. The sample aliquots were passed through suitable orifice sections and monitoring stations wherein the particulate matter in the samples were removed by passage through Chemical Warfare Service Type 6 filter papers. The collection efficiency of each experimental fiber bed was determined by measuring the amount of radioactivity collected on the upstream and downstream monitor filters. Two means of obtaining these values were available. A field measurement was provided by the pistol-grip type of radiation survey meter, termed the "CP". The second means of calculating the filter efficiency was from the results of actual laboratory analysis of the radioactivity on the monitors. An excellent agreement was obtained between these two techniques. A statistical analysis was made of approximately two hundred monitoring runs which were performed for the purpose of evaluating the collection efficiency of the plant sand filter. These routine determinations were accomplished in the same manner as that outlined for the fibrous glass units and covered a period of approximately twenty months. The analysis revealed that the precision of the radiation meter and the laboratory values was ± 0.29 per cent and ± 0.27 per cent respectively.

Filter Formula

The measured collection efficiencies for the various types of glass fiber beds were correlated with the controlled variables of superficial air velocity, bed depth, and fiber packing density by a mathematical expression very similar to the general equation which may be derived for the initial filtration characteristics of a laminar-type filter operating at only its rated superficial velocity. Assuming the aerosol to be homongeneous and that each filter layer removes the same average fraction of particles, the rate of deposition is:

$$-\frac{dW}{dN} = MW \qquad (1)$$

where: W = weight rate of flow of particulate matter.
N = number of filter layers (comparable to transfer units).
M = a constant = the average collection efficiency per layer.
α = the over-all collection efficiency.

Subscripts "i" and "o" refer to inlet and outlet conditions.

Rearranging and then integrating the relation over the total filter results in:

$$\int_{W_i}^{W_o} \frac{dW}{W} = -M\int_{O}^{N_o} dN \qquad (2)$$

$$\ln -\frac{W_o}{W_i} = -MN_o \qquad (3)$$

$$\frac{W_o}{W_i} = -e^{-MN_0} \qquad (4)$$

Since, by definition:

$$\alpha = \frac{W_i - W_o}{W_i} = 1 - \frac{W_o}{W_i} \qquad (5)$$

$$\alpha = 1 - e^{-MN_0} \qquad (6)$$

Such an expression applies only to laminar-type filters in which the physical characteristics of each layer are the same; for example, a unit comprised of a number of CWS

filter papers. Glass fiber filters, however, involve other parameters, such as the bed depth and packing density.

For purposes of convenience the collection efficiency was expressed in terms of dimensionless "decontamination factor" involving common logarithms rather than natural logarithms. Thus;

$$\alpha = 1 - 10^{-DF} \qquad (7)$$

By introducing the decontamination factor into the exponential equation given above and including the parameters of superficial velocity, bed depth, and packing density, an expression suitable for the filtration of fibrous glass beds in the velocity range studied may be obtained. In mathematical form:

$$DF = -\log (1-\alpha) = CL^a \rho_p^{\ b} V^c \qquad (8)$$

where: L = bed depth, inches

ρ_p = packing density, lbs/ft³.

V = superficial velocity, ft./min.

C = a constant, the dimensions of which are such that the decontamination factor is dimensionless.

a, b, c = empirically determined exponents.

To determine the exponents for each type of glass fiber, the variance in the collection efficiency was measured in a series of test runs in which only one parameter was varied at a time. Thus, to obtain the velocity exponent, the same bed depth and packing density of a test unit were retained throughout a number of runs, so that the following correlation of efficiency and superficial velocity was in effect:

$$DF = -\log (1-\alpha) = C' V^c \qquad (9)$$

and

$$\log DF = \log [-\log (1-\alpha)] = c \log V + \log C' \qquad (10)$$

By plotting the data on a logarithmic graph of decontamination factor versus velocity and measuring the slope of the line, the velocity exponent was obtained. This procedure is illustrated in Figure I, wherein the velocity exponent of Owens Corning "AA" Fiberglas, a fiber having a mean diameter of 1.3 microns, was determined by employing test units with a packing density of 0.6 pounds per cubic foot and bed depths of 0.5, 1.0, 1.5 inches. A similar procedure was employed to determine the exponents for the other parameters.

Table II

EFFICIENCY PARAMETERS FOR GLASS FIBERS

$DF = CL^a \rho_p^{\ b} V^c$

Fiber Number	Fiber Diameter (microns)	C	a	b	c
AA	1.3	4.6	0.8	1.0	—0.2
B	2.5	....	....	....	—0.25
55	15	0.085	0.9	1.1	—0.4
115K	30	0.054	0.9	0.9	—0.4
450	115	....	....	....	—0.5

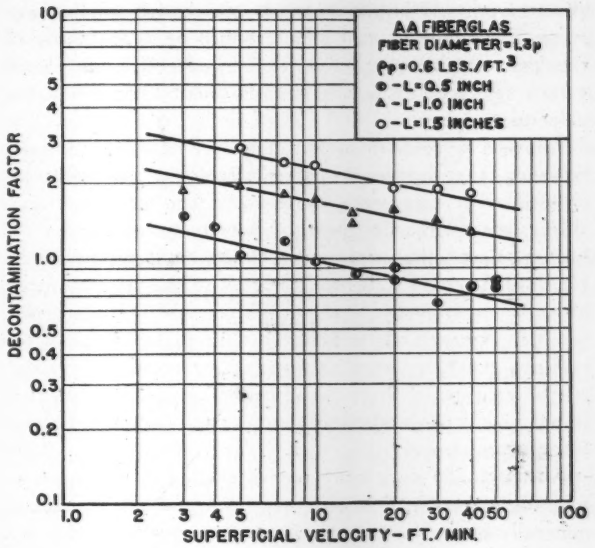


Fig. 1. Graph of Decontamination Factor vs. Superficial Velocity.

Data Correlation

A compilation of the collection efficiency data for the more promising glass fibers is presented in Table II. For each type of glass fiber, the value obtained for the bed depth exponent was less than one, which demonstrates the effect that particle size distribution has on collection efficiency. During the passage of a gas stream through a fibrous filter, the size distribution of the suspended particulate matter continually undergoes incremental changes brought about by particle deposition. Since the collection efficiency of an incremental layer of the filter is a function of the size of the particles passing through it the median particle diameter continually shifts toward the particular size that most readily penetrates the filter. The net result is that the filter increment required to achieve a given collection efficiency increases in depth as the particle size distribution changes, or, in mathematical terms, the bed depth exponent for a given heterogeneous aerosol is less than one.

The value for the packing density exponent varied from 0.9 to 1.1. It is believed that the true value of this exponent is 1.0, and that the recorded variance was due to the experimental precision.

Throughout the velocity range of 0—75 feet per minute, the collection efficiency of any one type of fiber decreased as the superficial velocity was increased, indicating that the predominant mechanisms of particle removal were flow-line interception and diffusion of the particles to the fibers with their subsequent adherence. A consistent lowering of the velocity exponent with decreasing fiber diameter was obtained. Since the mechanisms of particle diffusion and particle impingement are influenced in opposite directions by an increase in velocity (flow-line interception is independent of velocity), and since the

effect of particle impingement is greater for smaller diameter fibers, the overall effect should be a flattening of the low velocity portion of the decontamination factor versus velocity curves and a consequent lowering of the velocity exponent.

Above a velocity of approximately 75 feet per minute, however, the degree of particle removal gradually increased with increasing velocity. Since practical considerations, primarily those of flow resistance and filter life, restricted the application of deep-bed filters at the Hanford Atomic Products Operation to the velocity range of approximately 25 feet per minute, this characteristic was not explored. It is believed that the reversal of the velocity exponent from a minus to a plus value was due to the transition from a diffusional process to particle impingement as the predominant, velocity-dependent, collection mechanism.

Although the data were not correlated on the basis of fiber diameter, it was observed that the efficiency was generally higher for the filter units having the smaller diameter fibers.

Flow Resistance of Glass Fiber Filters

The resistance offered by fibrous glass beds to the air streams passing through them was measured in a series of permeability tests in which atmospheric air was employed rather than the contaminated process-cell air. The pressure drop for each type of glass fiber was correlated with the operating variables according to the following relation:

$$\Delta p = K L^x \rho_p^y V^z \qquad (11)$$

where: Δp = pressure drop, inches of water
L = bed depth, inches
V = superficial velocity, ft./min.
ρ_p = packing density, lbs./ft^3.
K = a constant
x, y, z = empirical exponents

The exponents x, y, z, were determined in a series of pressure drops vs. velocity measurements which were made on a suitable number of filter beds, each of which had a different bed depth and packing density. Cross-plotting the data resulted in a general expression for the pressure drop of each type of glass fiber. The data for the fibers which were selected for detailed study are presented in Table III.

The bed depth exponents, as would be anticipated, were one. The velocity exponents were each one, demonstrating that laminar flow exists throughout the flow range (5 to 100 fpm) which was studied. The value for the packing density exponent was determined to be 1.5.

Table III
FLOW RESISTANCE PARAMETERS FOR GLASS FIBERS

$$\Delta p = K L^x \rho^y V^z$$

Fiber Number	Fiber Diameter (microns)	K	x	y	z
AA	1.3	0.082	1.0	1.5	1.0
B	2.5	.....	....	....	1.0
55	15	0.00043	1.0	1.6	1.0
115K	30	0.00020	1.0	1.5	1.0

Comparative Life Expectancies of Glass Fiber Filters

The proper design of a highly efficient fibrous glass filter involves not only an adequate knowledge of the characteristics previously outlined, but also sufficient information regarding the on-stream properties to insure a maximum life expectancy. When a particle is filtered from an airstream, it is assimilated within the bed and causes an incremental change in the operating characteristics of the filter by assisting in the removal of other particles and increasing the resistance to air flow. The low concentrations of radioactive and inactive particles in the process-cell air described above provided a convenient means of determining the filtration characteristics of fibrous beds under start-up conditions where filtration was due to the fibers alone and the effects of the filtered particles were immeasurably small. The use of the process-cell air to determine the comparative life expectancies of glass fiber units relative to the plant sand filter, however, would have been impractical. A methylene blue aerosol was therefore employed to provide a high dust loading and thus restrict the test period to a suitable time interval. It should be noted that, since the exact manner in which the assimilation of collected material continually changes the operating features of a filter is dependent upon the size distribution, concentration, and structure of the particles, the *quantitative* results of the methylene blue tests cannot be applied directly to field conditions involving particles of a different nature. The qualitative results, however, are extremely useful in the design of a filter having a maximum life expectancy.

Experimental Equipment

The methylene blue smoke that was employed as a test medium was generated by dispersing a dilute solution of the dye into the air and evaporating the resultant droplets. The formation of the liquid aerosol was accomplished by means of four aspirators, the design of which was originally proposed by Laskin and later modified by Enquist.[11] When the aspirators were positioned with their bases slightly immersed in the liquid, the passage of air through the jets at a pressure of 15 lbs./sq. in. resulted in the liquid being aspirated into the bases and ejected as a fine spray. The mist continuously formed by four aspirators was passed through a cyclone separator where the larger droplets were removed. The mist-laden stream was then diluted with large volumes of clean air in a dilution chamber which served to evaporate the water and stabilize the resultant smoke. The diameter of the solid particles so formed was a function of the dye concentration of the original solution. A 2 per cent solution

(11) Enquist, E. H., "Preliminary Design Calculation for Filter Material Tests with Radioactive Dusts," Naval Radiological Defense, Document No. AD-159(H) (9-14-49).

resulted in smoke particles having a measured mean diameter of 0.5 micron. The dust loading was 2 to 8 grains per thousand cubic feet of air.

Upon leaving the dilution chamber, the main stream was divided into eight parallel lines, each of which served a test unit. The parallel smoke streams passing through the fibrous glass units were individually metered in orifice sections, then collected into a header line containing a CWS box-type filter, and exhausted to the atmosphere. Pressure taps were incorporated at appropriate points in the filter units and the lead lines were brought to U-tube or inclined manometers. Sample ports were located directly downstream from the dilution chamber and at the extreme end of the header feeding the parallel units. These positions were operated continuously to verify the uniform dust loading of the gas entering the filter beds.

Calculation of the dust-loading of the smoke or the grains of dust entering a filter bed involved the measurement of the amount of dye collected on the monitor filters. Removal of the methylene blue from the filter paper was accomplished by applying suction to the face of the paper and slowly backflushing with 95 per cent ethyl alcohol. Flushing with water was prohibited by its strong tendency to "set" the dye in the paper. After the addition of water to the methylene blue solution, the alcohol was removed by distillation. The residue was made up to a known volume and then diluted to a concentrate suitable for analysis by a Beckman Spectrophotometer.

Efficiency Increase Studies

The concept of mechanical filtration as a dynamic process which culminates in the "plugging" of the filter bed was demonstrated by measuring the average collection efficiency and flow resistance during the passage of an incremental amount of smoke to a test filter. The cumulative grains of dust passing to the unit per square foot of filter area plotted against efficiency and pressure drop values at a superficial velocity of 25 ft./min. for 2 inches of Owens Corning No. 115K Fiberglas packed at 6 lbs./ft.^{3} are presented in Figure 2. The early portion of the pressure-drop curve is relatively flat, while the corresponding efficiency values increase rapidly. As the slope of collection efficiency curve flattens, the pressure-drop curve

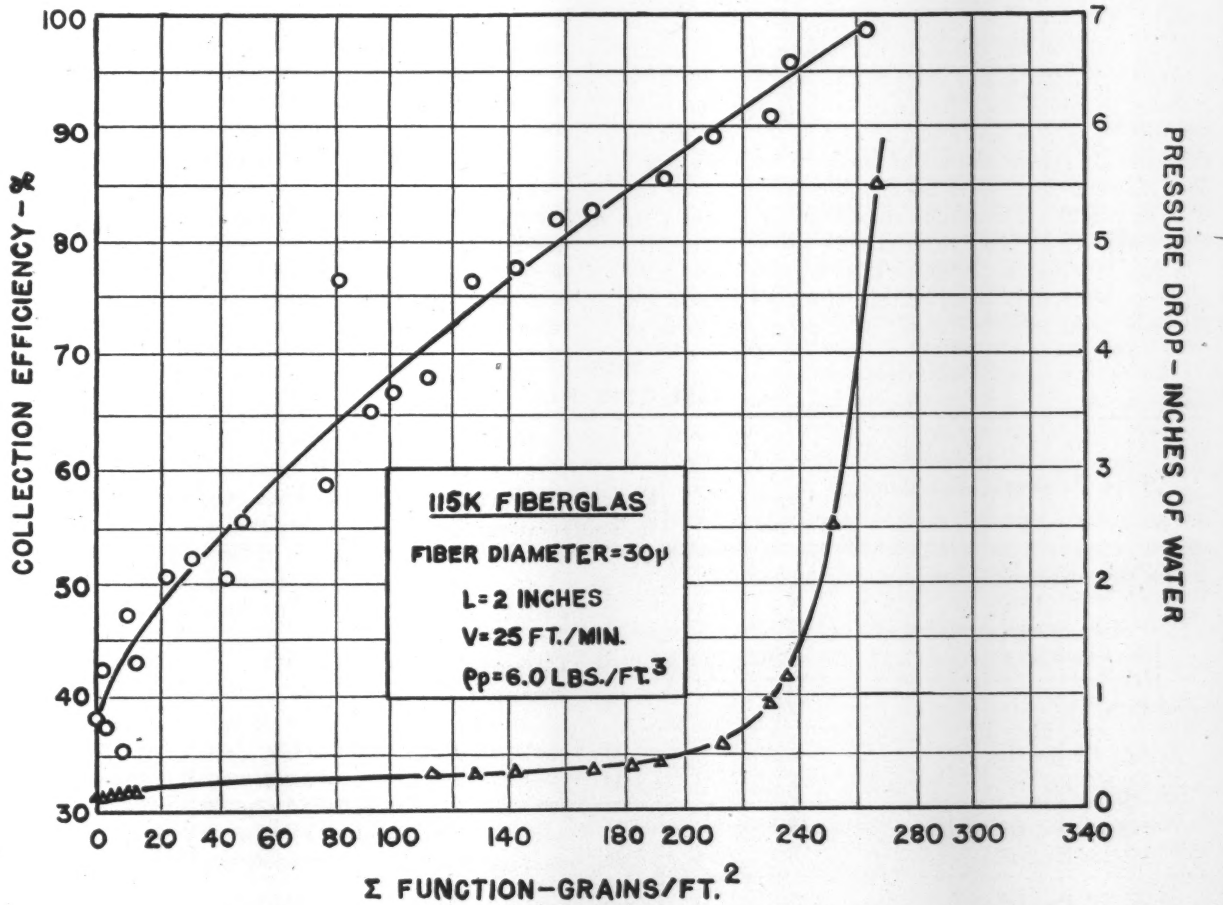


Fig. 2. Graphs of collection efficiency and flow resistance vs. cumulative grains of methylene blue passing to the filter per square foot of filter area.

becomes progressively steeper. Thus, the shapes of the two graphs can be interpreted in terms of one another. During the initial rapid rise of collection efficiency, the amount of material assimilated within the bed was not sufficient to bring about an immediate increase in flow resistance. Upon reaching high efficiency values, however, virtually all of the material approaching the unit remained within the bed and, consequently, built up the pressure drop at a more rapid rate.

Life Test Data

To provide sufficient information regarding the on-stream properties of glass fiber beds to permit the development of a highly efficient filter capable of operating for a much longer period of time than the plant sand filter, a series of tests were performed wherein the useful filtration life of the various fibrous beds was determined as a function of the quantity of smoke particles passed to the unit. The basis of a comparison chosen for the life expectancy tests was a model of one of the plant sand filters. The data which were obtained during one of the life tests are presented in Table IV.

Included in the table are the compositions of the various test layers, the depth of each test stratum, the velocity with which the unit was operated, the initial pressure drop of the bed components, the pressure drop increase to which the filter was carried, and the total quantity of aerosol which was passed to the unit during this time. In general the use of forefilters having a larger fiber diameter or a lower packing density increased the filter service life. The results show that the fibrous glass filter composed of "AA" Fiber at a density of 1.2 lbs./ft^3. and No. 55 Fiber at a density of 6 lbs./ft^3. would have a life approximately equal to that of a sand filter if the filtration areas were the same. If a protective layer of No. 55 Fiber at a density of 3 lbs./ft^3. is incorporated into the unit, the life of the filter will be approximately twice that of the sand filter. If a forefilter of No. 55 Fiber at a density of 1.5 lbs./ft^3. is incorporated, the life of the composite filter will be about 20 times that of a sand filter having an identical area. Since the glass fiber units are operated at approximately five times the linear velocity of a sand filter, the effective life extension is approximately four times that of a sand filter. If the assumption is made that this factor is applicable to the Hanford process-cell air conditions, a glass fiber filter can readily be designed which will efficiently filter the process cell particulate matter for at least fifteen years without an excessive increase in pressure drop.

The Weatherability of Glass Fibers

In addition to the on-stream filtration characteristic of glass fibers, the service life of a filter unit is influenced by fiber weatherability *i.e.* the degree to which it can withstand the effects of the conditions under which it is to be used. The large increase in surface area brought about by the formation of small filaments from a pound of solid glass results in a corresponding increase in its reactivity with acids, alkalies, or water. Weatherability is thus a function of fiber diameter and glass composition. It is advisable to consult the manufacturer concerning the weatherability of a particular type of glass prior to its use in a plant installation.

The Design of Glass Fiber Filters

A convenient method of co-ordinating and summarizing the material presented in the previous sections is to give an illustrative example of a filter designed to remove suspended particulate matter in the sub-micron size range with an efficiency of 99.99 per cent or greater. The filter formulation developed for the decontamination of the

Table IV
LIFE TEST RESULTS

Type Packing	Depth (inches)	Velocity (ft./min.)	Initial ΔP (inches of H_2O)	ΔP Increase (inches of H_2O)	Grains of M.B. to unit per sq. ft. of filter area at ΔP increase
Sand Filter Model					
VI 20-40 mesh	3	5	1.25	0.33	
V 8-20 mesh	12	5	0.55	0.73	
IV 4-8 mesh	6	5	0.06	4.50	
III 4-¾"	12	5			
II ⅜"-¾"	12	5			125
AA, 1.2 lbs./ft^3.	0.25	25	0.80	0.13	
55, 6.0 lbs./ft^3.	8	25	1.58	4.50	125
55, 6.0 lbs./ft^3.	8	25	1.63	0.20	
55, 3.0 lbs./ft^3.	5	25	0.33	4.50	300
55, 3.0 lbs./ft^3.	5	25	0.29	0.08	
55, 1.5 lbs./ft^3.	14	25	0.27	4.50	3000

Table V

GLASS FIBER VENT FILTER INFORMATION

Approximate Superficial velocity—20 fpm.

The gas stream contains varying amounts of sub-micron particles and acid vapors; the latter often reach a volume concentration as high as 50%.

Layer	Type Fiberglas	Packing Density (lbs/ft³)	Bed Depth (inches)	Initial Efficiency (per cent)	Initial Pressure Drop (Inches of Water)
Bottom	115K	1.5	12	39	
Second	115K	3.0	10	53	0.24
Third	115K	6.0	20	93	1.34
Clean-up	AA	1.2	1	99.9	2.20
Total			43	99.99	4.0

vent gases from one of the Hanford process vessels is presented in Table V. The unit is 2.5 feet by 5.5 feet with an overall height of 4.3 feet. The cross-sectional area, 12.5 ft²., was defined so that under conditions of maximum gas flow the superficial velocity is approximately 20 feet per minute. Weatherability data indicated that the chemical resistivity of the 115K and AA Fiberglas would be satisfactory under the service conditions. The depth and packing densities of the various strata were based upon the relationships discussed above and were selected to provide a maximum service life, a filtration efficiency in the order of 99.99 per cent, and a pressure drop of four inches of water at the rated air velocity.

It should be noted that the force necessary to compress large amounts of glass fibers may be considerable and will influence the structure of plant-scale containers. The resilience of the material requires that these forces be continually maintained. The necessary compressive force to restrain No. 115K Fiberglas to a given density, for example, is related to the packing density over the range of 1 to 9 lbs./ft³. by the following expression:

$$C_t = 2.1(\rho_p - 0.6)^2 \qquad (12)$$

where: C_t = restraining compressive force, lbs./ft².

ρ_p = glass fiber packing density, lbs./ft³.

To permit an evaluation of this vessel vent filter under actual service conditions, monitoring equipment was installed in a gallery adjacent to the process.[12] Aliquots of the upstream and downstream gases were drawn through the filter pressure lead lines through the canyon wall and passed through CWS Type 6 monitoring filters. The system used short, well-sloped lines and permitted reliable sampling. The data which were obtained with this apparatus are shown in Table VI.

In the efficiency range, with only approximately one part ten thousand passing the filter, it is quite difficult to obtain definitive efficiency values. Even with the expedient of using different flow ratios through the two monitors it is difficult to obtain a set of monitoring filters for which the upstream sample is not too "hot" or the downstream sample too "cold" for accurate activity readings. Consequently, a majority of the efficiency determinations can be expressed only as "greater than" values. The data demonstrate, however, that the efficiency of the fiber glass bed is greater than 99.9 per cent and probably near 99.99 per cent. The efficiency values obtained agree well with the calculated design figures.

This filter unit has been in operation for slightly more than two years. There have been no maintenance requirements nor has there been any change in the operating characteristics.

(12) Blasewitz. A. G., *et al*, "Decontamination of the Dissolver Vent Gases at Hanford," General Electric Co., Hanford Atomic Products Operation, Document No. HW-20332 (2-16-51).

Summary

Fixed-bed filters, formulated from fibrous glass media have been developed and selected at the Hanford Atomic Products Operation as the method best filling the requirements for the particulate decontamination of the process gas streams. The parameters affecting the dependent variables, collection efficiency and flow resistance, have been thoroughly evaluated for the more promising glass fibers. A comparison of the useful filtration life to be expected from the various types of fibrous units has been made in a series of tests using a methylene blue aerosol. Based upon these data, plant scale equipment capable of operating at a higher superficial air velocity than the plant sand filters and with a greater efficiency, a lower flow resistance, and a greater life expectancy has been designed and installed. The collection efficiency of the plant units has been determined to be in the order of 99.99 per cent. The first fibrous glass units have been in operation for 2½ years and there have been no maintenance requirements nor any significant change in the performance characteristics.

The use of glass fiber filters, of course, need not be restricted to the filtration of radioactive materials. Fixed-bed filters formulated with glass fibers can be advantageously employed whenever sub-micron particles, present in air streams at low concentrations, must be removed with a very high efficiency.

Acknowledgement

The authors wish to express their appreciation to the management of the General Electric Company and to the Atomic Energy Commission for permission to publish this paper.

Table VI

GLASS FIBER FILTER MONITORING DATA

Date	Upstream Monitor		Downstream Monitor		Efficiency (per cent)
	Flow (cfm)	Activity (mrep/hr.)	Flow (cfm)	Activity (mrep/hr.)	
12-19-50	1.0	6000	1.0	<5	>99.92
12-19-50	1.0	1500	1.0	<5	>99.67
12-21-50	1.0	4250	1.0	<5	>99.88
12-21-50	1.0	33000	1.0	8	99.97
12-21-50	0.5	9750	1.5	<5	>99.98
12-22-50	0.5	6000	3.0	<5	>99.98
12-22-50	0.5	135	3.0	<5	>99.39

Discussions of Papers in November Air Repair

DISCUSSIONS OF PAPER BY CHARLES E. BILLINGS et al. ENTITLED "PERFORMANCE OF THREE TYPES OF FABRIC DUST COLLECTORS"

The authors of this paper deserve the thanks and appreciation of all concerned with dust collection problems for a well-rounded and factual investigation and presentation. Practically the only imperfection in the investigation is the fact that the efficiency tests on Collector A tabulated in Table II did not include the cleaning cycle, making the results not strictly comparable to Collectors B and C, which did include the cleaning cycle; and even this imperfection is pointed out and discussed by the authors.

It is unfortunate that there is so little published data on the efficiency of collectors of this class on atmospheric air. As the authors point out, the efficiency of new cloth on atmospheric air is in the neighborhood of 70 to 80%, and this increases to "over 90%" after 400 hr. operation. The region between 90% and 100% may be of importance in many applications. I am personally aware of other unpublished data, wherein efficiency of 97% on a particle count basis was obtained after about 1000 hr. operation. These data are not comparable, being on a count rather than on a weight basis, but it is probably safe to assume that the weight efficiency would be as high as or higher than the count efficiency. There are several installations of collectors of this class handling air containing only atmospheric dust loading, and it is to be hoped that a quantitative investigation of one or more of these units in actual service will soon be made.

KNOWLTON J. CAPLAN
St. Louis, Missouri

Comparison of these three types of fabric dust collectors on the basis of equal filtering velocities provides an excellent picture of some of their basic characteristics. This should contribute to a much needed better understanding of their proper application and operation by industry. However, as mentioned by the authors, they are not comparable at equal velocities from an economic standpoint. The Type B and probably also the Type C (although to lesser extent) must operate at a higher filtering rate to justify their greater per unit area cost.

Reference is made to constant volume in the Type B as resulting from continuous cleaning, meaning elimination of the necessary differential between start and stop settings of a pressure switch. This is certainly true when dust load and atmospheric conditions are constant. They are frequently not constant, however; and in some cases the volume can vary widely with continuous cleaning, and the more constant volume would result from control by pressure drop. In fact, it is then confined to the effect of ½ to 1-in. water gauge, representing insignificant difference in the usual dust collecting system with a total pressure drop of 10 or 12 in. or more. This paper refers to a differential of 1 to 2 in., but that much is not usually necessary in plant installations.

A clarification of possible interest may be made on the remark to the effect that on some applications of the Type B, the rings must operate continuously. These are the applications where the dust load is so great that a continual repelling of the depositing dust is necessary to hold the pressure drop down to a practical point, and where there is no danger of overcleaning. Examples of this type of application are recovery of the total output of impact pulverizers and pneumatic conveying systems.

The subject of atmospheric dust is of particular interest to this meeting and I would like to add to the data presented, which is based on 400 hr. for priming. An experiment was made a few years ago which indicated that after about 2,000 hr. the efficiency of wool felt reached 98.5% by count with a face velocity of 18 to 21 ft./min. at a pressure drop of 4 in. water. Subsequent operation of the reverse jet with various pressure switch settings reduced the pressure drop to as low as 1.5 in. with a resulting increase in face velocity. The minimum efficiency was 93% by count. This suggests that with the very small differential which would be practical on atmospheric dust load, not exceeding ¼ in. water gauge, that efficiencies in the high nineties by count could be maintained. To shorten the very long priming period required for wool felt, artificial priming with filter aids, such as the asbestos referred to with the Type A, has been suggested. However, I do not consider it practical to load felt for reverse jetting with anything but the material to be filtered, as it would too rapidly be removed without replacement.

H. J. HERSEY, JR.
New York, N. Y.

The collector designated as Type A is a sectional, continuous-type collector which normally operates with both bag sections on, with each section periodically shut off to permit cloth cleaning. During the short period of time while one section is shut off, the other section handles the entire load. The control of shut-off dampers and cloth-cleaning mechanisms is normally through regular time cycle or by differential pressure controller. This method of operation utilizes the total cloth area to better advantage. Note that the larger the number of bag sections provided, the less the variations in resistance (due to a lesser increment of the total cloth area being shut off during cleaning periods).

The collector designated as Type C is a compartmented, cloth-tube collector of a basic design used for many years, the original design having come from Europe. While there are a number of modified designs as concerns tube suspension, air-flow control, cloth-cleaning mechanisms, sequence timing, etc., the fundamental principle of all designs is similar. This compartmented type of cloth-tube collector has been extensively used on a wide diversification of industrial dust and fume problems in other than the flour milling industry. Current practice is to rate this type of collector at lower filtering velocities, particularly when handling more finely divided dusts and fumes. This type of collector may also be controlled through time cycle or differential pressure, as well as mechanically.

The use of atmospheric dust for evaluating the collecting efficiency of fabrics, while interesting, has relatively little bearing on results in normal industrial practice. Woven cotton fabric is not normally used for atmospheric air cleaning, whereas felted fabrics are sometimes so applied. The filtration principle varies between woven filter fabrics and felted filter fabrics. Collectors using woven fabrics utilize the fabric as a foundation or backing upon which to accumulate the dust pack which serves to a large degree as the filter media. This is verified by the results secured with atmospheric dust after 400 hr. of operation and by the increased collecting efficiency when cotton sateen was coated with asbestos fibres. As with all woven fabrics, the fabric construction, thread count, yarn size, fabric weight, etc., all have influence on the collecting efficiency. The use of the term "cotton sateen" is broad and inconclusive unless the fabrics tested are of the same specifications and construction.

Felted filter fabrics are not dependent upon the dust pack for filtration effectiveness but accomplish filtration by the density and permeability of the fabric. Such fabrics are frequently used for atmospheric air cleaning, personal protective devices, etc.

No information is included as to the condition of the filter fabric for the three collectors tested. The condition of the fabric, that is, whether new or previously used, would influence the pressure losses. This question is indicated by the resistance of Collector A, which would be considered low in general industrial practice, particularly in the cleaned condition. Assuming this cloth to be new at the start of the tests, a more extended period of operation would probably build up the residual pack and result in less swing in pressure loss. The pressure loss in any intermittently cleaned cloth collector is governed by the dust loading, dust physical and chemical characteristics, filtration rate, air temperature and moisture content, and the cloth cleaning frequency. Thus the cloth cleaning frequency of any intermittent-type collector must be governed by and adjusted to field operating conditions on specific applications to prevent large swings in pressure loss between clean and dirty condition. This swing in pressure loss must be maintained within the limits of the maximum collector loss for which the exhaust system was designed. The cloth-cleaning action of any collector using woven fabric should not be of sufficient intensity nor magnitude to clean the fabric to new condition, but should merely serve to increase the permeability of the dust pack without seriously disturbing the residual coating. Too severe an action will result in a greater swing in pressure loss and will also lower the over-all collecting efficiency. This is to some degree witnessed by synthetic-fibre filter fabrics in constructions at present available which do not accomplish over-all collecting efficiency comparable to that of cotton.

The paper does not include fabric collectors of the screen-frame type which are extensively used in both intermittent and continuous operating design. A relatively recent development is a reverse-air-cleaning, cloth-screen collector. This self-cleaning collector uses woven fabric bags and accomplishes cloth cleaning through a travelling manifold equipped with an integral, reverse air blower. This collector provides continuous-system operation with uniform air volume and pressure loss.

The paper is indicative of results with three fabric collectors of

specific design, using the specific filter fabrics with which they were equipped and at the stated filtration velocities, with the types and concentrations of dust used, and with the cloth cleaning methods and frequencies specified. The results should not be interpreted as indicative of the performance of such collectors under the many varying conditions which influence collector performance in industrial operating practice.

W. O. VEDDER
Pangborn Corporation
Hagerstown, Maryland

(Continued from page 196)

Gas Cleaning for Steel Making

TABLE II
Performance Characteristics of Slag-Wool Filters
All Tests at Temperatures of 600 to 800°F
Loadings from 0.02 to 0.34 gr./scf. Air

Filter Characteristics			Resistance		Efficiency (By Weight) %	A %	$\frac{A^a}{\Delta p}$	No. of Tests
Thickness Inches	Density lb./ft.^{3}	Velocity fpm.	Initial Inches of Water	Increase Due to Fume Filtration Inches of Water				
1/8	20	140	1.8	4.6	88[b]	22.0[b]	3.9[b]	3
1/8	40	220	2.7	17.9	85	2.7	0.16	2
1/4	15	220	4.0	16.4	95	2.5	0.15	4
1/4	20	130	1.9	5.0	87[b]	10.0[b]	1.8[b]	4
1/4	20	220	5.5	14.6	92	1.5	0.10	5
1/4	25	220	7.1	12.9	92	0.8	0.06	3
1/2	5	220	2.2	18.2	85	4.1	0.22	2
1/2	10	150	2.7	8.0	78	3.8	0.81	10
1/2	10	220	4.4	14.3	95	3.9	0.28	17
1	5	220	4.0	15.6	92	4.6	0.28	3

(a) $A = \frac{\text{Upstream loading} \times \text{Flow rate} \times \text{Time of Test} \times \text{Efficiency}}{\text{Filter weight}} \times 100$

Δp = Pressure rise, inches of water

(b) 2 samples

Filter studies have been directed towards obtaining a maximum filter performance coefficient value A which we have defined as the upstream loading (L) times the efficiency (E) times the time of operation (t) and the volume of air flow through the filter (Q) all expressed as per cent of filter weight (w) or $A = \frac{LEQt}{w}$. When this value is divided by the over-all resistance rise Δp for a given run, an index of filter performance is obtained from which its life and resistance can be predicted. Some typical results are given in Table II. From these data it can be seen that efficiencies as high as 95% have been obtained at resistances within an economical operating range.

After extended studies in the laboratory, studies have been made in the field at two different plants, one on a cold metal and the other a hot metal furnace. We were gratified to find that the laboratory results to date have in general been confirmed by the field studies. By electron micrograph measurements it was found that the fume generated in the laboratory is considerably finer and gave shorter filter life than that obtained in field testing.

Based on these investigations, which are still in a preliminary state, we have developed a pilot model unit which will be in operation early this winter at an eastern steel plant. This unit is designed to handle 500 to 1000 cfm. of gas at high temperature and involves the use of a continuous moving bed of rock wool shown schematically in Fig. 3.

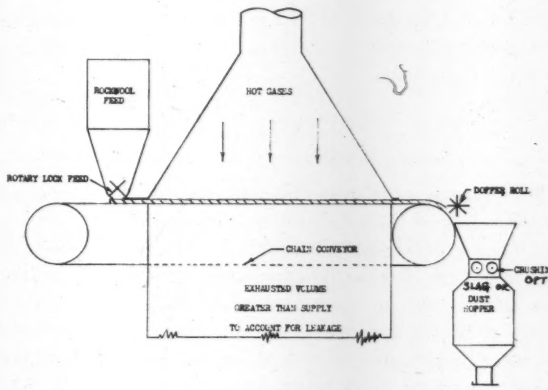


Fig. 3. Schematic Diagram of Travelling Filter Utilizing Reworked Slag-Wool.

One of the most important items that has been developed from the laboratory and field studies has been the fact that slag wool is capable of continuously withstanding temperatures as high as 1000°F. and it can be reworked to remove the accumulated fume. To-date we have successfully obtained as many as 7 to 10 recycles of the original material, and are developing our program for full scale equipment design with this as an extremely important factor in the potential application of the method. Because of limited data we are not presenting details of our cleaning method and procedure but it is worth-while to note that the reworking and cleaning is essential to the economical application of the wool. Economics of the slag-wool process will be presented in detail in a later report.

Acknowledgments

The writer wishes to express his thanks to Messrs. I. L. Beauchamp and W. D. Small for their assistance in the experimental studies and calculations. Credit is due the American Iron and Steel Institute for financial support of the work through their Subcommittee on Air Pollution Control under the chairmanship of Mr. W. O. Everling, American Steel and Wire Co. Arrangements for tests in the field were made with the aid of Mr. Everling and Dr. A. D. Brandt of the Bethlehem Steel Company.

(Continued from page 222)

Impingement Baffle Scrubber

A second case shows even more clearly the agglomerating affect of an electrostatic field. A direct comparison was obtained by first operating a Peabody test unit directly on the raw gas, and then operating the same test unit on the gas discharged by a hot precipitator which was receiving the raw gas, as follows:

Parallel Operation	Hot Precipitator	Peabody Test Unit
Raw Gas to Cleaner	3.7 gr./ft.^{3}	3.7 gr./ft.^{3}
Gas Leaving Cleaner	1.0 gr./ft.^{3}	1.15 gr./ft.^{3}
Series Operation		
Inlet Gas	3.7 gr./ft.^{3}	1.0 gr./ft.^{3}
Outlet Gas	1.0 gr./ft.^{3}	.14 gr./ft.^{3}
Solids Removed by Scrubber		86%

The scrubber operating directly on raw gas removed somewhat less of the solids than a hot precipitator. However, when operating on gas that had passed through the precipitator, the scrubber removed about 86% of the solids that it was incapable of removing when supplied directly with the raw gas. The solids so removed were substantially all fume that had been conditioned in the precipitator to the point where it could be caught by the scrubber.

Hydrogen Sulfide

The preceding discussion has been confined to removal of particulate matter from a gas stream. However, it is recognized that certain gases vented to atmosphere may contain components such as H_2S which would cause an atmospheric pollution problem. In one instance in which the discharge by a chemical company of a waste gas containing H_2S would cause not only a nuisance but also a pontential health hazard, our engineers, working with the client, developed a tower with an efficient impingement tray. A 4 tray tower was designed over which sodium carbonate was circulated, and upon installation the H_2S content of the gas was reduced to less than 5 ppm. Other problems of absorption of acidic components from waste gases may be solved in the same manner.

Summary

For a properly designed impingement scrubber, the following factors should be incorporated:

1. Subdivision of the gas into many small streams,
2. Directed impingement of the gas stream against a wetted target, and
3. Close contact between gas and liquid.

Our Impingement Baffle Plate employs all of these factors for maximum efficiency and flexibility of operation. Towers have a wide range of successful application in cleaning gases discharged to atmosphere.

AIR POLLUTION CONTROL ASSOCIATION

President

GORDON P. LARSON '55
Director, County of Los Angeles Air Pollution Control District
Los Angeles, California

First Vice President

H. KENNETH KUGEL '55
Chief Engineer
Div. of Smoke Regulation and Boiler Inspection
Washington, D. C.

Vice Presidents

W. A. CARTER '55
Technical Engineer
Detroit Edison Company
Detroit, Michigan

R. L. IRELAND '56
Chairman, Executive Committee
Pittsburgh Consolidated Coal Co.
1300 Leader Bldg.,
Cleveland, Ohio

JOHN E. BROWN '56
Air Pollution Control Engineer
Milwaukee, Wisconsin

Past President

THOMAS C. WURTS '55
Director
Allegheny County Bureau of Smoke Control
Pittsburgh, Pa.

DIRECTORS

HENRY E. ALDRICH '55
Manager, American Boiler & Affiliated Industries
New York, N. Y.

G. A. DAVIDSON '55
Vice President
Standard Oil Co. of California
San Francisco, California

RALPH W. BOURNE '56
Chief Combustion Engineer
Louisville Smoke Commission
Louisville, Kentucky

MILLER G. STEWART '56
Road Foreman of Engines
Washington Terminal Co.
Washington, D. C.

H. L. WAGNER '56
Vice President in Charge of Engineering
Detroit Stoker Company
Monroe, Michigan

H. A. BELYEA '55
Industrial Hygiene Engineer
Ontario Department of Health
Toronto, Ontario, Canada

BASIL HORSFIELD '57
Vice President
Reynolds Metals Corp.
Sheffield, Alabama

BENJAMIN LINSKY '57
Supervising Engineer
Bureau of Smoke Inspection & Abatement
Detroit, Michigan

HERBERT H. ULRICK '57
Chief Smoke Regulation Engineer
Sanitation Commission
Omaha, Nebraska

ELMER P. WHEELER '57
Industrial Hygienist
Monsanto Chemical Co.
St. Louis, Missouri

Treasurer
H. C. DAVIES

Executive Secretary
HARRY C. BALLMAN

4400 FIFTH AVENUE - PITTSBURGH 13, PA.

AIR
POLLUTION
CONTROL ASSOCIATION